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issued by the
Norwegian Government.
Scale = 1:1,000.000.
östl. v. 20° Greenwich
Hammerfjord
Kvalö
Helgö
VANDÖ
ARNÖ
Helgöfjord
70°
Rebbenäsö
Vandsund
Kjelmangen
RINGVASÖ
RENÖ
Ulöen
Kvalsund
Grötsund
Rotsund
Vengsfjord
Ulsfjord
Erstfjord
KVALÖ
Tromsö
Lyngen
Lyngenfjord
Kaafjord
Balsfjord
Kamfj.
Sörfjord
Malangen
Balsfjorden
SENJEN
Maalsnäs
Balsfjord
Pigtind
Stortfjord
Gisund
Maalselvfjord
Sagelv
90 m
Höltind
Maalselven
Rismaalstind
Omasvare
Tagvand
220 m
Fjeldträsk
69°
Salbergfjord
Ruostatjeld
Mauktind
Övrebygd
Övergaard
Lf. Ruostavand
Ruosta elv
Bakkehaug
Div. elv
Store Ala
Bardo elv
Lerkul
Salangen
Bardo
Gruahögden
Baadkjepen
Högskar elv
Frihedsli
Lavangen
Strömsmoen
Kälbirvare
Namna
Store Jerta
Julusvare
Rubben
Dyoddaraks
Rissovare
Nunnis
Stagenuvs
Pjolnorgard
Altevand
Ofotenfjord
Torneträsk
20°
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THE FACE OF THE EARTH

(DAS ANTLITZ DER ERDE)

BY EDUARD SUESS

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PART III

THE SEA

CHAPTER I

CONFLICT OF OPINION REGARDING THE DISPLACEMENT OF THE STRAND: TERMINOLOGY AND GENERAL OBSERVATIONS

Strabo. Dante. Celsius and Linnaeus. Nordenankar. Playfair and Leopold von Buch. Goethe. Lyell and Darwin as supporters of the theory of elevation. Bravais and Eugène Robert. Chambers and Domeyko; renewed expressions of doubt. Theories based on gravitation. Adhémar and his successors. Summaries; Howorth. Terminology. Genuine case of dislocation in New Zealand. Plan of the following chapters.

We have descended from the mountains and stand on the seashore. The eye roams unchecked over the vast expanse of waters. A great wave approaches and seems about to reach us; suddenly its crest curls over, it plunges downwards, and with a dull roar, sweeps a little further on without wetting our feet. Then the water streams back, and a long green ridge of seaweed remains to mark the limit of its advance. Soon a second wave follows, then a third, and from time to time one somewhat higher than the rest, which whirls the seaweed further up the beach, and drives us back towards the foot of the cliff.

The roll of the waters is repeated like the chorus of a mighty song. The sublimity of the scene might hold us captive for whole hours. At length the crest of the wave breaks at a greater distance from us, and soon the lowest point of the ebb will be reached. Then the Ocean returns and all the bands of white shells, and the green coils of seaweed it had left behind, are again swept together by the ever advancing line of the waves, until after six hours of rising tide even the spot where we first stood is reached, and at last the sea washes once more against the foot of the cliff.

So to a stately measure the heavenly bodies cause the swaying Ocean to alternately advance upon the land and retire.

Let us now turn to the cliff. Here the traces of an older strand may be clearly seen, standing high above the existing level of the sea. For mile after mile they may be followed at a constant height, undisturbed by the nature or structure of the coast, over cliffs of limestone, granite, or ancient

volcanic ash, or late Tertiary detritus; they encircle as with a girdle, not only the mainland, but also the islands off its shores.

This is something very different from the crushing and overthrusting we meet with in the mountains, and very different from folding, which is determined by the strength and direction of the tangential stress, by the rigidity of the rocks, and the resistance offered by opposing masses, changing consequently in character as it passes from place to place. The phenomenon before us is of an altogether different nature, and if we recall the play of the tides with their rhythmic rise and fall in phases of half a day, then nature herself seems to suggest the question whether other forces may not exist capable of causing much more important oscillations and of much longer periods than that which we have pictured as driving us back to the foot of the cliff.

Many distinguished observers have answered this question in the affirmative; others have supposed that changes may have occurred in the volume of water in the Ocean; others, on the contrary, have imagined uniform and gradual movements of the solid land—*secular* movements, as they are generally termed. These conflicting theories have been advanced and adopted in turn according to the state of knowledge at the time or the views which happened to be in favour regarding the origin of mountain chains and the conditions of equilibrium of the sea-level.

The ancients were well aware that the sea once extended inland as far as the oasis of Jupiter Ammon, and that it covered all the low-lying ground from the Casius to the Red Sea: the polemic in Strabo's Geography (I, 3) bears striking witness to the zeal with which they sought to solve this problem. In accordance with Archimedes, Strabo asserted that the surface of all undisturbed water tends to correspond with that of a sphere, which has the same centre as the earth. Seas, he maintains, have no slope. He reproaches Eratosthenes with credulity for having believed on the evidence of certain engineers that the water on the two sides of the isthmus of Corinth stood at different levels. According to Strabo, not only islands and isolated mountains are subject to elevation, but also the mainland itself; on the other hand tracts of land of greater or less extent are liable to give way and sink towards the interior.—

Space would fail, were I to attempt to write the history of this discussion, which is as old as our science itself; yet as previously we illustrated the nature of volcanos and the diverse origin of earthquakes by certain selected examples, so now we will attempt by means of a few chapters of this history to bring into relief some at least of the successive aspects which this question has assumed.

Now, however, it is no longer to the mute eloquence of nature that we must lend an ear, but to the conflict of human opinion, sometimes loud-voiced enough.—

It is January 20, 1320. The bells of Verona ring in a bright Sunday morning, and the crowd greets with respect a personage of tall stature and earnest countenance, approaching with slightly inclined head to enter the chapel of Santa Helena: it is *Dante*.

All that can move the human soul the great poet has felt, and in the realm of imagination he has travelled farther than any mortal man before him. He has survived the loss of his Beatrice, and the loss of the emperor from whom he had hoped a better future for his country. Now flying from the hatred of his native city he has found a refuge at the court of the leader of the Ghibellines of upper Italy, Can Grande of the house of the Scaligeri. With a gift of description never before equalled he has led his astonished contemporaries to the heights of the blessed and the depths of the lower world; and now he returns to the starting-point of his mightiest creation, to the examination of that which is greater than all the conceptions of poetry, the actual constitution of the Universe.

Dante has to-day invited the whole educated world of Verona to listen to a discourse in this chapel, entitled 'De aqua et terra.' He proposes to discuss the relative position of land and sea, and as he tells us himself, every one came at his invitation, 'with the exception of a few, who feared by their presence to confirm the exceptional importance of others[1].'

But it is difficult for us, accepting as it were this invitation after an interval of more than five hundred years, to examine without prejudice the views of the great poet. It is not easy to free ourselves from that presumption of superiority with which we are wont to regard the efforts of a period so remote, in which nevertheless, with the assistance of Arabian science and the somewhat fragmentary remains of Aristotle, the foundations of the existing edifice were laid: a task accomplished, in spite of the paucity of observations, by the courageous and untiring efforts of the more eminent spirits to obtain a victorious comprehension of the Cosmos as a whole.

The work of recognized authority in Dante's time was the 'Speculum quadruplex' of the Dominican, *Vincentius* of *Beauvais*, completed in the year 1244. This monk, one of the ornaments of the court of Saint Louis, arranged the material in the cosmographical part of his encyclopaedia in accordance with the seven days of creation[2]. Vincentius points out the contrast which exists, in the genesis of the elements, between the *fiat lux* on the one hand, and the *congregentur aquae ut appareat arida* on the other. In the expression *congregentur aquae* he sees a condensation of the

[1] Quistione trattata in Verona da Dante Alighieri il dì 20. gennajo MCCCXX intorno alla forma del globo terracqueo ed al luogo respettivamente occupato dall' acqua e dalla terra; ed. Torri, Livorno, 1843, p. xlii, § xxiv.

[2] Bibliotheca Mundi, seu vener. viri Vincentii Burgundi ex ord. praedicat. episcop. bellovac. Speculum quadruplex, naturale, doctrinale, morale, historiale; fol. Bellerus, Duaci, 1624; lib. V, col. 307, et seq.

water vapour in the lower layers of the atmosphere, an accumulation of the resulting water in the hollows of the earth's surface, the awakening of the *vis inclinativa ad descensum*, or, as we should say, of the force of gravity, previously slumbering in the molecules of water. As the blood communicates with the heart, so all the waters flow into the sea. The surface of the earth is spherical, so likewise is that of the waters.

Thus far the conceptions of Vincentius are clear, and there is no fundamental difference of opinion among his successors. In continuing his examination of the curvature of the Ocean, Vincentius is led to reflect on the rounding of the surface of water in a goblet, and the spherical form of a drop. The fact that the shore may be kept longer in view from the mast of a ship than from the deck, seems to him a proof of the independent convexity of the surface of the sea, and from the presence of springs in the high mountains, he concludes that the Ocean must stand at a higher level than the mainland.

Thus Vincentius furnishes us with the first, though vague suggestion, of a force of cohesion, as seen in the law by which a drop is formed: this influences and indeed determines the form of the surface of the Ocean, which consequently does not depend solely on the action of gravity. We might almost say that he represents the Ocean to us as a single gigantic drop adhering to the globe [1].

Other investigators, as *Roger Bacon*, in his remarkable 'Opus Maius,' which he presented to Pope Clement IV in 1267, start from the unity of the *Centrum mundi* and the concentric arrangement of all the spheres of the Universe: this view received its clearest expression, so far as it refers to the Ocean, in that famous chapter, where Bacon shows that a goblet would be capable of containing more liquor in the cellar than in the taproom. Every point in the surface of a liquid, says Bacon, lies equally distant from the centre of the earth, every such surface is thus a part of a spherical surface; the nearer the centre, the smaller the radius of curvature, the more considerable therefore its elevation above the edge of the vessel [2].

Nevertheless the idea gained ground that the oceanic sphere possessed an independent form, its elevation above the mainland was held to be an incontestable fact, perceptible to the senses, and many authors spoke of it as rising in a definite asymmetrical ridge. Among these was *Brunetto Latini*, that teacher, who had instructed Dante 'how man may immortalize

[1] Op. cit. lib. VI, col. 377, cap. xii. 'Quod etiam Oceanus terram cingens in verticem sit coactus.' W. Schmidt justly lays emphasis on the importance of this passage, and on the contrast between *self-conformation* and *figure of the earth*; see his dissertation, Ueber Dante's Stellung in der Geschichte der Kosmographie, 8vo, Graz, 1876, p. 10, note.

[2] Fratris Rogeri Bacon, ord. minor., Opus Maius ad Clementem IV, Pont. Rom.; ed. Jebb, fol., Lond., 1733, p. 97, cap. x.

himself [1].' After the defeat inflicted by Manfred on the Florentines near Monte Aperti in 1260, Brunetto, who was also a distinguished statesman, retired into exile in France, where he remained until 1267, i. e. until after Manfred's death at the battle of Benevento. It was during this period that he composed his chief work 'Li Livres dou Tresor': in this also the theory of the elevation of the sea above the land was maintained, chiefly on account of the elevated situation of many springs [2]. But in Dante's case the intuition of a scientific mind gradually entered into conflict with the views of his beloved teacher, and that is probably the reason why Dante in the whole of his discourse 'De aqua et terra' does not once mention the name of any of his opponents [3].

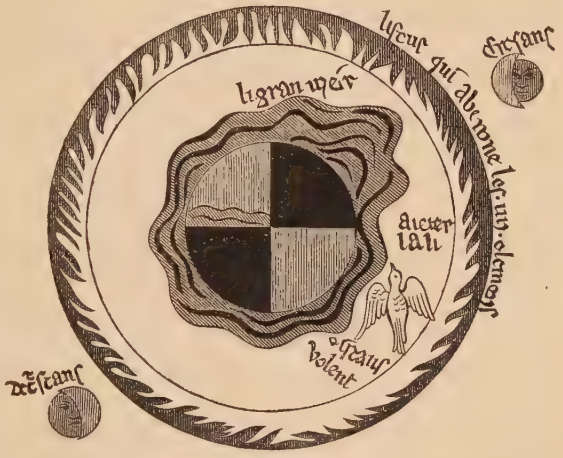


FIG. 1. Copied from Brunetto Latini: Li Livres dou Tresor, Chabaille Edition, p. 117.

Dante begins by enumerating the arguments of the rival schools, and shows that they lead to two alternatives; either the whole mass of water is situated eccentrically or there is a local swelling up of part of it. He asserts that neither of these hypotheses is tenable. If the mass of the Ocean were eccentric, then water must be capable of flowing both upwards and downwards. Let the points A and B (Fig. 2) represent the two centres. A mass of earth and a quantity of water falling from Z to the earth would proceed in different directions: but gravity is a property common to all bodies.

For the same reason a local protuberance of the Ocean is also impossible, for it would be at once dispersed.

The Ocean is thus concentric with the earth and every part of its surface is equidistant from the common centre. Since, however, the shores of the continents and the continents themselves rise above the surface of the

[1] Inferno, cant. XV, v. 82–85.

[2] Brunetto Latini, Li Livres dou Tresor, publ. par P. Chabaille, Collection de documents inédits sur l'histoire de France, publiée par les soins du Ministre de l'Instruction Publique, 4to, Paris, 1863. In particular liv. I, cap. cvi, pp. 114–116; also p. 169: 'et Mauritaine fenit en haute mer de Egypte; et commence cele de Libe, où il y a trop fieres merveilles; car la mer i est assez plus haute que la terre, et se retient dedanz ses marges en tele maniere que ele ne chiet ne ne decourt sor la terre.'

[3] Inferno, cant. XV, v. 119, 120: 'Siati raccomandato il mio Tesoro Nel quale io vivo ancora. . . .'

water, these parts of the earth must be higher than the Ocean. Again, it is evident that the earth rises from the Ocean owing to particular elevations of its mass, and not as the result of eccentricity, since in the latter case the dry land would be bounded by a circular outline, and this we know is not the case.

There exists then a true elevation of the land, and of this we must seek to discover the cause. '*Dico igitur*,' says Dante, '*quod causa huius elevationis efficiens non potest esse terra ipse; quia quum elevari sit quoddam ferri sursum; et ferri sursum sit contra naturam terrae*[1].' *The earth cannot elevate itself;* nor can the cause be water, fire, or air; the elevating force must therefore be sought in the heavens.

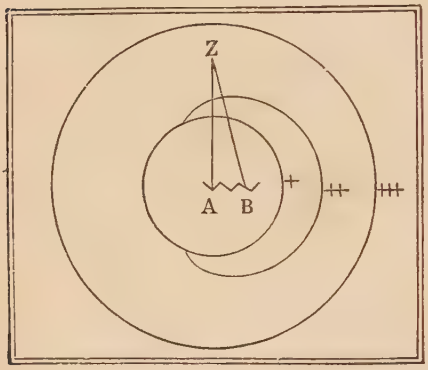


Fig. 2. Copied from Dante: *Quaestio de forma et situ aquae et terrae*, editio Torri, p. xxiv.
A Centre of the Earth and Heavens,
B Centre of the Ocean;
† indicates the Earth, †† the Ocean, ††† the Heavens.

In the starry firmament this force cannot for obvious reasons emanate from the moving stars, the moon, sun, or planets; it must therefore be sought in the fixed stars, which exercise this influence, either after the manner of magnets or by the production of active vapours. Dante thus adopts the system which had already been expounded in greater detail by *Ristoro d'Arezzo* in 1282; according to this not only must the irregularities of the earth's surface be ascribed to the fixed stars, but mountains and valleys present as it were a mirror of the various distances of these stars from the earth, in an inverted sense, like the impression of a seal in wax[2].

In conclusion, Dante reminds his hearers that the apparent sinking of the coast observed by the departing sailor simply results from the general curvature of the liquid sphere, and adds it has long been known that springs are not fed by water directly ascending, but are formed by the condensation of water vapour on the mountains[3].—

[1] Dante, Quistione, &c., § xx. De causa efficiente elevationis Terrae; ed. Torri, p. xxxvi.

[2] Ristoro d'Arezzo, La Composizione del mondo, testo italiano del 1282 pubblicato da E. Narducci, 8vo, Roma, 1859, p. 79. In addition Ristoro is aware of the erosive power of water, and of the existence of fossilized remains of marine animals: he even suggests the influence of earthquakes on mountain structure, p. 83, et seq.

[3] This was the opinion of Dante, the cosmographer; let us compare it with [the views expressed in] his poetry. Vincentius of Beauvais dedicates a whole chapter (lib. VI, cap. vii) to the question: 'Quorsum iniectus lapis erit casurus, si perforatus sit terrae

Dante died in the following year, A.D. 1321. Let us hasten through the centuries towards a period when as the result of increased observation that varied and almost uninterrupted succession of diverse theories arose, which has not even yet reached an end.

In 1692, a young nobleman of Lorraine, *Benoist de Maillet*, was appointed French consul in Egypt; transferred in 1708 to Leghorn, he was afterwards sent on several occasions to the Levant, and thus became acquainted with the coasts of the Mediterranean. He observed indications of the retreat of its waters, and concluded that the volume of the Ocean suffers a continuous diminution: his results were not published till after his death in 1748[1].

Meanwhile attention was being directed in Sweden to facts of the same kind. In 1702, the physicist *Hjärne*, having discovered that the coast-line was receding, caused marks to be cut in several of the rocks in order to measure the rate of the movement. *Emmanuel Swedenborg* believed the sea to be sinking, and this to a greater extent in the north than in the south: in proof of this he called attention to the rapid increase in the area of Lapland. The idea of a change in the form of the liquid envelope of the planet here finds definite expression. In a letter of May 21, 1721, addressed to Jacobus a Melle (von Honig) of Lübeck, Swedenborg asserts, not indeed as a fact, but as a hypothesis worthy of consideration, that 'the water of the Ocean sinks towards the poles and (probably) rises towards the equator, and that islands previously separated from the land have been united with it by the sinking of the sea[2].'

Swedenborg took no part in the discussion of this question which arose a few years later in his own country: his name is scarcely mentioned in connexion with it. The poet Dante, after he had achieved the greatest creations of his genius, was still capable of high endeavour in the pursuit

globus.' It will rest in the centre, says Vincentius. It appears to many authors of that time to be an almost insoluble problem that an element so light as fire should appear in the interior of the earth, since the spheres are otherwise arranged according to the weight of their matter. Let us consider in addition the conception of Jerusalem as the centre of the inhabitable world, and the relations of the central fire of the earth to hell. Lucifer, cast down headlong, reaches the earth at a point exactly opposite to Jerusalem, and travels to the centre of the globe; *the principle of evil is now identified with the force of gravity*. Cf. the sketch of the centre of the earth by Philalethes, Uebersetzung von Dante's Göttlicher Komödie, 3. Aufl., 1877, Taf. II, III.

[1] Telliamed, ou Entretiens d'un philosophe indien sur la diminution de la mer, avec un missionnaire français; vol. I, 1748, vol. II, 1755. Some absurdities and a certain lack of criticism as regards the facts enumerated may have contributed to cause this work, in which e. g. Bronn's Terripetal theory is clearly anticipated, to fall too early into oblivion. Quatrefages has done it justice in his 'Charles Darwin et ses précurseurse français,' 8vo, 1870, p. 19–32.

[2] Epistola nobiliss. Emanuelis Swedenborgii ad Vir. celeberr. Iacobum à Melle. Acta Literar. Suec. 1, Upsala et Stockholm, 1721, p. 196; also by the same, Miscellaneae observationes circa res naturales, 8vo, Leipzig, 1722, I, p. 47.

of physical truth: the naturalist Swedenborg on the other hand after a long scientific career turned his attention towards the spiritual world. The poet may attempt to cross the limits of the earthly, he is lord in the kingdom of dreams; but if the man of science, whose heavier foot is accustomed to the firm ground of proof, venture into this realm, then while he thinks he is perceiving realities visions are his masters.

In the region of the Mediterranean, two distinguished hydraulic engineers, *Manfredi* of Bologna and *Zendrini* of Venice, had meanwhile made observations, which led to results entirely opposed to those of de Maillet, but in harmony with the suggestion of Swedenborg. In their opinion the surface of the Mediterranean, so far from being in process of sinking, was slightly rising. The discovery of a marble pavement beneath the cathedral of Ravenna, eight inches below high-water mark, and the constant flooding of some of the lower parts of the Doge's palace in Venice, as well as the condition of the church of Saint Mark, were the evidence of this movement. Manfredi's treatise, 'De aucta maris altitudine,' did not appear till after his death in 1746: in this he explained the rising of the sea-level as due to the great quantity of sediment yearly carried down to the sea by rivers [1].

Let us now return to Sweden.

It is the autumn of the year 1729. In the university garden of Upsala sits a poorly clad student of medicine and jots down the names of the plants. His poverty is such, that, as he confessed later, he cannot afford to have his shoes mended, and is obliged to put paper in them that he may not walk on the bare sole. This is *Linnaeus*, son of the vicar of Stenbrohult, now in his twenty-second year. An ecclesiastic of some note, *Olaf Celsius*, subsequently provost of the chapter of Upsala, and now engaged in preparing a history of plants mentioned in the Bible, addresses the student, questions him concerning a number of botanical names used by Tournefort, is delighted with his knowledge and takes him back to his house. The young man's zeal soon wins for him the full favour of Celsius and the intimate friendship of his nephew Andreas [2].

[1] E. Manfredi, De aucta maris altitudine; De Bonon. Scient. et Art. Instituto atq. Acad. Commentarii; tom. I, pars 2, Bonon., 1746, pp. 1–19. Manfredi had made his observations in 1731, and died not long after, in 1739; cf. op. cit. tom. II, pars 1, 1745, p. 237 et seq. Ravenna, according to the testimony of Vitruvius, was moreover entirely built on piles; to what extent even in early times its low situation gave rise to complaints is shown by the passage quoted by Manfredi from Sidonius Apollinarius, an author of the end of the fifth century, who calls Ravenna a marsh where, contrary to all the laws of nature, 'muri cadunt, aquae stant, turres fluunt, naves sedent, aegri deambulant, medici iacent, algent balnea, domicilia conflagrant, sitiunt vivi, natant sepulti.' The graves thus extended downwards into the water.

[2] Afzelius, Linné's eigenhändige Aufzeichnungen über sich selbst, aus dem Schwedischen v. Lappe, 8vo, Berlin, 1826, p. 12.

It was in 1724, while still a youth, that Andreas Celsius had visited the shores of the gulf of Bothnia. He had observed the retreat of the sea at Huddiksvall, Piteå, and Luleå. At Torneå he had been shown to his astonishment that the harbour constructed in 1620 was already useless. Mariners pointed out places, now scarcely navigable for boats, on which great ships had once sailed. Near Langelö and in other places he saw rings to which ships had once been made fast, now at a distance from the sea. From these facts he inferred a sinking of the sea-level to the extent of about forty-five inches (133 cm.) in the century.

Let us now pass over the fourteen years which followed the meeting in the botanic garden. Linnaeus and Andreas Celsius have both become professors in ordinary at the University of Upsala. They have travelled much in Europe, and Celsius has enjoyed the friendship of Manfredi in Bologna; he has also taken a prominent part in the measurement of degrees made by the French in the north; they have each visited Lapland; each enjoys the highest reputation in the learned world. They agree together to put forward in University lectures the much discussed and much opposed views of Celsius on the shrinking of the sea[1].

Linnaeus delivered his lecture on April 12, 1743, Celsius followed on the 22nd of June in the same year: in giving an account of these discourses I will take first that of Celsius, since he is the greater authority on this subject, and presents us on this occasion with a summary of his views.

Celsius adopts the following line of argument:—

We must consider our planet in three successive states: the first is that of inundation, the last that of conflagration, and between these is an intermediate state. As regards the state of inundation, which commenced very long ago, we have information of various kinds. We now live in the intermediate state, but everywhere we may observe signs of the retreat of the sea; its volume is diminishing, and so we are hastening to the last state, that of conflagration: the sun has already entered upon this, the planets are in various stages of the intermediate state, more or less removed from inundation and conflagration.

Linnaeus adds to this, as a kind of supplement, the following:—

The Lord did not create many individuals nor were they scattered over the whole world—to what end the creation of many when the same object may be attained by means of *one* pair or even *one* individual? Year by year the sea recedes, and the outlines of the mainland are correspondingly

[1] C. Linnaei Oratio de Telluris habitabilis Incremento, et A. Celsii Oratio de Mutationibus generalioribus quae in Superficie Corporum Coelestium contingunt, 8vo, Lugd. Batav., 1744; for the actual facts also: A. Celsius, Anmerkung von Verminderung des Wassers in der Ostsee und dem östlichen Meere; der kön. schwed. Akad. d. Wiss. Abhandl., &c., auf das Jahr 1743, translated by A. G. Kästner; V, Hamburg, 1751, pp. 25–37.

extended. Originally the mainland was only a little island containing everything which the Creator had appointed for the use of the human race. This island, that is to say Paradise, we may imagine as a lofty mountain under the equator; over the slopes, from foot to snow-covered summit, every species of plant found the climate suited to it. As the mainland increased in size the seeds of these plants, often of peculiar and specially adapted structure, were distributed by winds, rivers, and birds.

Andreas Celsius died in 1744, the very year in which these two lectures appeared in print in Leyden. The conclusions of Linnaeus were on all sides favourably received, owing to their conformity with biblical tradition, whereas those of Celsius, although the outcome of the same general view, called forth the most violent opposition, particularly his reference to the approaching destruction of all living things. Affairs reached such a point, that when the state historian, *Olaus Dalin*, brought forward fresh proofs from historical sources in favour of Celsius, the Swedish diet expressed its disapproval of his theory by a special decree.

This, however, did not temper the keenness of the controversy. Many supported the views of Celsius; some attempted to explain the shrinking of the Ocean by evaporation into space, others returned to an older theory of Pontoppidan, revived of late years by Saemann, according to which the fixation of water vapour had taken place during the consolidation of the globe. On the other side, the leading opponent of the theory was *Browallius*, the learned bishop of Åbo. He pointed out that the low island of Saltholm, near Copenhagen, was in existence as far back as 1230, and consequently that the observations made by Celsius further to the north were not confirmed in the south: he showed also that in the north itself, on the coast of Finland, in the district of Åbo and in Björneborg's Län, trees of great age stand but a few feet above the actual sea-level; as for instance in Bjernoskärgaard, where a tree was felled which stood only four feet above the water-level although it was 310 years old. To these very important and indisputable facts I shall recur later[1].

The work of Bishop Browallius made a deep impression, and treatises on this subject became less numerous: finally, in 1792, that is almost fifty years after the two discourses of Celsius and Linnaeus, Admiral *Nordenankar*, who possessed a thorough knowledge of the Baltic, advanced new views on the undoubted sinking of the water-level. The work in which these were published failed unfortunately to find the appreciation it deserved[2]. According to Nordenankar the Baltic must be classed with

[1] J. Brovallius, Betänkningar om Vattensminskning, 8vo, Stockholm, 1755; published in German under the title 'Historische und physikalische Untersuchung der vorgegebenen Verminderung des Wassers und Vergrösserung der Erde,' &c., translated by K. E. Klein, 8vo, Stockholm, 1756.

[2] J. Nordenankar, Tal. om Strömgångarne i Öster-Sjön, hållet for kongl. Vetenskaps

inland lakes, the universal characteristic of which is that they stand at a higher level than the Ocean, just as the Mälar stands at a higher level than the Baltic. For this reason the decrease of the water is less surprising. It was not till communication was established between the Baltic and the North Sea through the Öresund and the Belts that the shrinkage of the water began: but at what period this connexion was effected we do not know, nor do we know when the waters of the Baltic, either by steady eflux or by a sudden outburst, will be brought into equilibrium with the Ocean; and not till this happens will the sinking of the water-level come to an end.

No fewer than two hundred rivers flow down from the surrounding land into the Baltic, and the water-level consequently varies with the year and the season. Steady winds accelerate discharge into the North Sea or check it, according to their direction, and thus affect the water-level.

Nordenankar has thus the credit of calling attention for the first time to the peculiar conditions which prevail in the Baltic, and the important influence of the fresh water which flows into it.

In Italy, meanwhile, a fresh approach had been made to the earlier views of Swedenborg.

The first volume of the works of the mathematician *Frisi*, published in Milan in 1782, contains a remarkable chapter 'De aucta et imminuta Marium Altitudine.' The author concludes from the observations of Celsius and Manfredi that the sea-level in the north is sinking, while in the Mediterranean it is rising. Distinguished investigators had, it is true, expressed the opinion that the mainland of Scandinavia is being raised by the force of a subterranean fire (Runeberg), but the elevation of such vast districts and such mighty mountain chains cannot take place without great and prolonged concussions of the earth or without the subterranean fire somewhere making its appearance, and even then, such movements would be very unequal in extent. Frisi further observes that although all seas with free communication must adapt themselves to the form of some continuous curve, yet an increased velocity of rotation would produce subsidence of the sea-level towards the poles. Such an acceleration is experienced by all bodies in process of condensation, which rotate about a definite axis[1].

Even in the case of Italy doubts arose. *Breislak* examined the now

Academien, vid Praesidii nedläggande, 18. Jan. 1792, 8vo, Stockholm, 1792. My attention was drawn to this treatise, now very rare, by Dr. D. G. Nathorst and Dr. J. A. Ahlstrand, librarian in Stockholm. A German translation exists under the title 'Die Strömungen der Ostsee.'

[1] P. Frisii Operum tomus I, Algebram et Geometriam analyticam continens, 4to, Mediolani, 1782, pp. 270–276.

classic example of the temple of Serapis at Puzzuoli; he was obliged to admit that no satisfactory explanation had been found, and in the French edition of his Travels in Campania published in 1801 he suggests the theory that the land itself had sunk five meters and had then risen again to the same extent. The translator *Pommereuil*, it is true, adds, 'This notion seems to be a jest; it is like cutting the Gordian knot because we cannot unravel it[1].'

The views of Frisi were opposed by *Playfair* in 1802, chiefly on the ground that coral reefs had been met with in the tropics below the existing sea-level; and returning to the older theory of Lassaro Moro, Playfair came to the conclusion that in Sweden the land was indeed in process of elevation. At the same time he emphasized the absence of trustworthy observations and the difficulty of obtaining them. The views we now regard as established, he remarks, are merely provisional and will be altered and corrected as knowledge advances[2].

Leopold von Buch soon followed with much greater decision in the same path. In the last days of September, 1807, he travelled from Tornea to the south. 'It is certain,' he wrote then, 'that *the surface of the sea cannot sink*; the equilibrium of the seas simply does not permit of it. Since, however, the phenomenon of diminution cannot be doubted, there remains, as far as we can see at present, no other course than to admit that *the whole of Sweden is being slowly elevated*, from Frederikshald to Åbo and perhaps even to Saint Petersburg[3].'

A change of opinion was beginning to make itself felt. The *theory of desiccation*, as we will call the doctrine of de Maillet and Celsius, was gradually giving way to the *theory of elevation* advocated by Playfair and von Buch.

We must not, however, imagine that the desiccation theory was at once abandoned. On the contrary, for a brief season it attained greater popularity than ever before. This was at the conclusion of the great wars, at the beginning of the last century, when millions of men were expecting the end of the world on July 18, 1816. Just as the individual, weakened physically by want of food or poverty of blood, is subject to mental disturbances in which depression, anxiety, and undefined presentiment of death struggle for expression, so the exhaustion of the people at that time might be measured by the irresistible force with which the idea of the immediately impending end of all living things took possession of whole

[1] S. Breislak, Voyages physiques et lithologiques dans la Campanie; traduit par le général Pommereuil; Paris, 1801, II, p. 170, note.

[2] The detailed treatise is contained in note xxi to Playfair's edition of J. Hutton's Theory of the Earth, Edinb., 1802.

[3] L. v. Buch, Gesammelte Schriften, herausgeb. v. Ewald, Roth u. Eck, II, p. 504. The 'Reise nach Norwegen und Lappland' appeared in 1800.

nations, as by an intellectual epidemic. The newspapers took particular pleasure in discussing the theory of Celsius which, condemned years before as pessimistic, because it prophesied the destruction of all life, now suddenly reappeared to comfort tormented humanity, by the prospect of many thousands of years of existence. The dreaded date passed by; a little polemic followed, and then the whole incident dropped into oblivion [1].

The theory of elevation, however, had as yet by no means attained supremacy. Many of the most distinguished geologists of the time regarded it with disfavour. Cuvier and Brogniart, who had proved the repeated alternation of marine and fresh-water deposits in the neighbourhood of Paris, nowhere speak in their works of elevation or subsidence of the land. The Cretaceous, so they say in substance, is deposited by a *first sea*; this withdraws (*se retire*), fresh-water deposits succeed, . . . *another sea*, populated by other Mollusca, returns (*revient*) to retire once more (*se retire*), &c. [2] The same expressions were employed by Omalius d'Halloy in 1813 [3], and later in 1827, when *Constant Prévost* undertook to dispute before the French Academy the results of these stratigraphical investigations; authoritative at that time, he too did not base his position on the theory of elevation. On the contrary, he doubted whether the presence of intercalated fresh-water formations could be regarded as an indication of the complete withdrawal of the sea, and attempted to explain the whole stratified succession around Paris simply by a repeated subsidence of the waters, thus returning to the fundamental idea of Celsius, now based on other arguments and clothed in a new form [4].

Even in 1822, *K. von Hoff* himself, the conscientious critic who had devoted himself particularly to the investigation of such questions in Germany, was unable to adopt the theory of von Buch: he also believed that the sinking of the sea must necessarily be a universal and uniform

[1] Seel, Vom Weltuntergange, mit Beziehung auf die verkündete Wasserabnahme der Erde, 8vo, Frankfurt, 1817; W . . . n in the Mainzer Zeitung of the 15th February, 1817, &c. Even at the beginning of this century discussions took place on the cause of the universal diminution of the waters, which was considered to be fully established as the cause of these phenomena; so for example, Poiret, Conjectures sur les causes de la diminution des eaux de la mer, Journ. de Phys., LX, an XIII, pp. 226-237; Patrin, Remarques sur la diminution de la mer et sur les îles de la mer du Sud, op. cit., pp. 306-323; Poiret, op. cit., in the next volume, pp. 17-22.

[2] Cuvier et Brogniart, Description géologique des environs de Paris. The geological part was first published by Brogniart, 1808, in the Annales du Musée, and then independently in 1811, later with Cuvier's 'Ossements fossiles.'

[3] Omalius d'Halloy, Note sur le gisement du calcaire d'eau douce dans les départements du Cher, de l'Allier et de la Nièvre; Journ. de Phys., 1813, LXXVII, p. 104 et passim.

[4] Constant Prévost, Les continens actuels ont-ils été, à plusieurs reprises, submergés par la mer? Compt. rend., IV, 1827, pp. 249-346.

phenomenon; von Buch's 'bold idea' he regarded as 'a truly desperate means of explanation[1].'

This judgement won the full approbation of Goethe, who in this connexion dedicated to von Hoff a remarkable essay on the temple of Serapis. 'For what, after all,' wrote Goethe, 'is all this shoving up of the mountains but a mechanism which gives no aid to the understanding and no play to the imagination? Mere words, without any corresponding ideas[2].'

'The earth cannot raise itself,' says Dante, 'that is contrary to its nature': there is a singular parallelism between these words and those of Wolfgang von Goethe written 500 years later. No one, in the history of the human intellect, stands above these two men; indeed, few stand beside them. Their keen eyes perceived the difficulties, but even they were not able to find any satisfactory solution. The pressing need for explanation brought about a return to the theory of elevation. In the year 1834, von Hoff also conformed to the new theory of the gradual elevation of continents, yielding to the force of fresh data, and won over by the theory of the elevation of volcanos and other mountains, which had meanwhile been further developed by Humboldt, von Buch, and their contemporaries.

The theory of elevation soon received the most important support from the investigations of Charles Lyell and Charles Darwin.

Charles Lyell travelled in the summer of 1834 to Sweden, satisfied himself of the truth of the alleged facts, and pointed out, even in his first accounts, that the evidence of a rising of the land is much clearer in the north than in the south[3]. At a later period, he inclined to the view, based chiefly on Nilsson's observations, that the elevation was greatest in the north of Scandinavia, decreased towards the south, and disappeared near Södertelje, a few miles to the south-west of Stockholm, but from this point subsidence set in and continued to the southern end of the peninsula, so that a tilting movement is thus in progress, and the limb south of the axis is much shorter than that to the north of it[4].

During the years 1832 to 1836, *Charles Darwin* accomplished his memorable voyage to the Pacific Ocean and to South America. The discovery of the structure of coral reefs led him at first to suppose that an extremely extensive subsidence was taking place in tropical regions over the greater part of the floor of the Pacific Ocean. Darwin attempted even

[1] K. E. A. von Hoff, Geschichte der durch Ueberlieferung nachgewiesenen natürlichen Veränderungen der Erdoberfläche, I, 1821, p. 447; II, 1834, p. 316 et seq.

[2] Wolfgang v. Goethe, Geologische Probleme und Versuch ihrer Auflösung. The essay on the temple of Serapis bears the title 'Architektonisch-naturhistorisches Problem.'

[3] C. Lyell, On the Proofs of a gradual Rising of the Land in certain Parts of Sweden. The Bakerian Lecture, read Nov. 27, 1834, Phil. Trans., 1835.

[4] e. g. in Principles of Geology, 11th ed., 1872, II, p. 190.

to represent on a map the distribution of areas of elevation and subsidence within these regions over the whole world [1].

A visit to the coast of South America, however, led to the discovery of a rising movement affecting the whole southern part of the continent down to about lat. 30° S., and this, judging from the successive terraces left by the sea, must in Darwin's opinion proceed *intermittently* [2].

The wide distribution of this phenomenon in space and its intermittent character were the two facts which began to suggest fresh doubts. The principal argument in support of the theory of elevation was indeed the local variability in the change of level experienced by the strand, and now the range of the proofs began to exceed the limits of the premises.

Bravais had asserted that two strand-lines in the Alten fjord, near Hammerfest, were not horizontal, and that the slope of the higher terrace was greater than that of the lower; but this evidence could no longer be regarded as conclusive. Élie de Beaumont, in a detailed report, certainly thought he had succeeded in showing that Bravais' observations indicated some connexion between the rise of the Scandinavian chain and the emergence of the littoral terraces; but the same report gives evidence of the distribution of similar terraces over the whole of northern Europe, and thus simultaneously supplies the refutation of this hypothesis. Further, it has since been shown that Bravais' observations were incorrect. The terraces near Hammerfest are just as closely parallel to the existing sea-level as everywhere else in Norway, and Bravais seems to have brought into the same line of measurement fragments of strand-lines and terraces which were really distinct [3].

The 'Commission scientifique du Nord,' of which Bravais was a member, also included the geologists *Durocher* and *Eugène Robert*. The report of Bravais, so completely in accord with the views prevalent at the time—erroneous, none the less, as was subsequently shown—found recognition on all sides; while the complete and invaluable collation of the facts furnished by Eugène Robert received scant attention. This work was laid

[1] C. Darwin, The Structure and Distribution of Coral Reefs, 1st ed., 8vo, 1842.

[2] Id., Geological Observations on South America, 8vo, 1846, p. 26, et passim.

[3] Rapport sur un mémoire de M. A. Bravais relatif aux lignes d'ancien niveau de la mer dans le Finmark (M. Élie de Beaumont rapporteur); Compt. rend., 1842, XV, pp. 817–849. In opposition to these views it will suffice to quote, among recent publications, T. Kjerulf, Einige Chronometer der Geologie, aus dem Norwegischen übersetzt von R. Lehmann, Samml. gemeinverständl. Vorträge v. Virchow und Holtzendorff, XV. Serie, Heft 352, 353, 1880, p. 14, and in particular K. Pettersen, Terrasser og gamle Strandlinjer, 3. bidrag, Tromsö Museum's Aarshefter, III, 1880, pp. 30–36; the same, translated by Lehmann in Zeitschr. f. d. ges. Naturwiss., LIII, 1880, pp. 815–822. This treatise was probably not yet known to v. Dechen when he spoke on this subject before the Niederrheinische Gesellschaft für Natur- und Heilkunde at Bonn on November 8, 1880.

before the Académie des Sciences in 1844[1]. It shows for the first time the extension of the phenomenon over the whole northern region, and although the author has nowhere ventured to draw the final conclusions from his observations, yet he evidently perceived the insufficiency of the prevailing theory.

Eugène Robert concludes his report with the following summary:—

1. The vestiges of ancient strand-lines do not appear to be uniformly distributed over the globe; in the southern hemisphere they seem to be comparatively rare.

2. They appear to become more frequent as we approach the poles; but this may simply mean that they are better preserved in these regions, where a scanty population, lacking our great industrial resources, has effected scarcely any change in the land it occupies.

3. They also become more sharply marked the more remote they are from the equator; but here again, as Robert suggests, an explanation may be found in the fact that the atmosphere and vegetation exert a less destructive action on the rocks in the arctic regions.

4. The ancient sea-margins for which the evidence is most conclusive attain the greatest height (162 to 195 meters) towards the north[2].

This work of Eugène Robert, which might have had a most stimulating influence, has been almost completely overlooked. Nevertheless, the wide distribution of the terraces became increasingly apparent, and it was precisely those who dedicated themselves to the special investigation of this class of facts, who were least able to repress their doubts regarding the ancient theory of elevation.

In 1848, *Robert Chambers* published a very instructive work on ancient sea-margins, containing a comparative study of the terraces of North America, Great Britain, France, and Norway. The author lays stress on the fact that no case of elevation observed during the existing period has affected an area at all approaching in extent that indicated by these ancient terraces[3]. He remarks:—

'The recession, accession, and second recession of waters indicated here, do not necessarily imply risings and fallings of our island, but may be

[1] E. Robert, Recueil d'observations ou recherches géologiques, tendant à prouver, sinon que la mer a baissé et baisse encore de nouveau sur tout le globe, notamment dans l'Hémisphère Nord, du moins que le phénomène de soulèvement, depuis l'époque où il a donné naissance aux grandes chaînes de montagnes, n'a plus guère continué à se manifester que d'une manière lente et graduelle; Compt. rend. 30 Juillet 1844, XIX, pp. 265–267.

[2] Voyage de la Commission scientifique du Nord en Scandinavie, en Laponie, au Spitzberg et aux Feröe pendant les années 1838, 1839 et 1840 sur la corvette 'La Recherche,' publié sous la direction de Paul Gaimard; E. Robert, Géologie, vol. X, pp. 194–195.

[3] R. Chambers, Ancient Sea-Margins, as Memorials of Changes in the relative Level of Land and Sea, 8vo, 1848, p. 320.

accounted for if we suppose some distant ocean bed sinking, then rising, then sinking again. Perhaps it may be some such latent change which has produced those immersions of forests and those wearings of coasts, with which English geologists are familiar. I feel, at least, a particular difficulty in admitting partial subsidences of land in the British Islands, when I see such uniform terraces around their coasts, as, in that case, deflexions from the true lines ought to have been conspicuous, which I am sure they are not.'

Rejecting for these reasons a local explanation, Chambers suggests that the extensive subsidence in the region of coral islands, that is, in the torrid zone, must cause the ocean waters to flow away from the poles. This is, so far as I know, the first attempt to bring into causal connexion the formation of atolls in the tropics and that of terraces in the higher latitudes.

In the same year, 1848, a description of the terraces of the coast of Chili, by Domeyko, appeared. The author made a direct comparison between these and the terraces of Norway. Although, according to Bravais, the terraces of the Alten fjord are far from horizontal, and although the lines marking the recent sojourn of the sea occur at very different heights, and at places so remote as Coquimbo on the one hand and the Alten fjord on the other, yet in both these regions the number of lines is very limited. We are led, therefore, to suppose that these phenomena are in no way dependent on local causes, but are connected with circumstances which influence the great revolutions of the globe, and affect both hemispheres simultaneously [1].

The following year, 1849, Dana, having completed his great voyage in the northern part of the Pacific, expressed his belief that the rise is greatest towards the north pole: the opposite movement towards the equator [2].

While the theory of elevation thus gained no support from a wider knowledge of the characters of these phenomena, a new school of thought arose, which inquired seriously into the question of the invariability of the conditions which determine the equilibrium of the Ocean. Very different causes have been suggested from time to time as capable of producing a universal alteration in the form of the oceanic surface: in all of them the force of gravity plays a leading part. I will therefore include all views of this kind—using an expression of James Croll's in a slightly extended sense—under the common name of *gravitation theories*.

The controversy between Dante and his opponents turned on a question of gravitation. To the gravitation theories belong also the views of Swedenborg. At a later time, when Halley's theory was in favour, *L. Bernard* supposed that the 'terrella,' which Halley conceived to be

[1] Domeyko, Mémoire sur le terrain tertiaire et les lignes d'ancien niveau de l'Océan du Sud, aux environs de Coquimbo (Chili); Ann. des Mines, 1848, 4e sér., XIV, pp. 153–162.

[2] J. S. Dana in Wilkes, U.S. Explor. Exped. 1849, X, pp. 670, 677.

moving independently within the hollow body of the earth, thus causing the displacement of the magnetic poles, was also responsible for changes in the form of the oceanic surface[1]. In 1804, *Wrede*, starting from the assumption that the centre of gravity of the globe is not necessarily coincident with its centre of figure, proceeds to show that the position of the former may be altered by the transport of sediments and various other causes. But this will bring about a change in the surface of the Ocean[2].

These various views may all be included in the group of gravitation theories, as well as those embodied in the important works of Adhémar.

Bertrand and Wrede sought the cause of the alteration within our planet or upon its surface, Adhémar on the other hand outside it, in its relations to other members of the solar system; his theory is thus based on considerations similar to those involved in the explanation of the tides.

The work which laid the foundation of this theory appeared in 1842[3]. Its main outlines are essentially as follows:—

The inherent heat of the planet is scarcely appreciable at the surface, and may be regarded as constant. The warmth of which we are sensible is almost exclusively derived from the sun. Any given place receives this heat during the day only, losing it again by radiation at night, so that with an equal duration of day and night the amount of heat received during the day and that lost during the night balance each other. The length of the day is thus one of the most important elements in the temperature of a place. At the south pole the hours of the night exceed those of the day by 168 in the year; it thus receives less sunshine, is consequently colder, and presents conditions far more favourable to the accumulation of ice than the regions around the north pole, where the hours of the day are more numerous by 168 than those of the night. This state of things is dependent on the position of the earth with regard to the sun, and on its movement. Owing to the precession of the equinoxes, the equal duration of day and night in all latitudes would recur at the same point on the earth's orbit at intervals of 25,900 years, but since the simultaneous displacement of the perihelion must be taken into account, this period is reduced to about 21,000 years. While, in our hemisphere, the sum of spring and summer is now some days longer than the sum of autumn and winter, at the end of half this period, that is in 10,500 years, these relations will be reversed. In the year 1248 of our era, the equal duration of day and night coincided with the perihelion; since that time the

[1] L. Bertrand, Renouvellements périodiques des continens terrestres, 8vo, an VIII, pp. 274–300.

[2] E. F. Wrede, Geognostische Untersuchungen über die südbaltischen Länder, besonders über das untere Odergebiet, nebst einer Betrachtung über die allmählige Veränderung des Wasserstandes auf der nördlichen Halbkugel der Erde und deren physischen Ursachen; 8vo, Berlin, 1804.

[3] J. Adhémar, Révolutions de la mer, 8vo, Paris, 1842.

northern hemisphere has been gradually growing colder, the southern warmer. Up to the year 1248 this circumstance caused the continuous enlargement of the ice-cap which surrounds the south pole; by the formation of this cap the centre of gravity of the planet was displaced, and the oceans were drawn towards the south. This explains the greater expanse of ocean in the south, and the predominance of land towards the north. After 10,500 years, that is in about the year 11,748 of our era, the same state of maximum refrigeration and maximum submergence will be reached by the north pole.

Thus the planetary movement would determine *a periodic transference of the ice-cap from one pole to the other*, and an accompanying submergence of the corresponding hemisphere.

It must, however, be observed that this conclusion is refuted by historic testimony. For if the northern hemisphere has actually been in process of cooling since the year 1248, and its ice-cap therefore increasing, then, since about one-seventeenth of the period preceding the maximum accumulation of the seas in the northern hemisphere has now already elapsed, some rising of the waters should be observed on all the northern shores, and this is not the case. Adhémar certainly felt this contradiction, and made an attempt to meet it. He supposed that the Antarctic ice needed a very long period to disappear, and even suggested that a sudden adjustment might be possible as soon as the centre of gravity crossed the plane of the equator. The phenomena in the Baltic might perhaps be ascribed to local conditions.

In spite of this and of many other weak points, Adhémar's work was most stimulating in its influence as a serious attempt to explain, by a single and consistent theory, three great phenomena, namely, the predominance of water in the southern hemisphere, the periodic return of glacial epochs, and the universality and constancy of oscillations of strand-line. *Croll* in England, *Schmick* in Germany, and many others, have amended and developed Adhémar's views, all retaining the main idea of an accumulation of the sea, which is periodically transferred from one pole to the other. On the other hand, distinguished climatologists, and in particular *A. Woeikof*, have definitely asserted that the facts on which Adhémar and his successors have based their theory, are incompetent to produce such extreme changes of climate as they have been supposed [1].

[1] J. Croll, Climate and Time in their geological relations, a Theory of the secular changes of the Earth's climate, 8vo, London, 1875. This principal work had been preceded by a number of smaller treatises which appeared, since 1864, chiefly in the Phil. Mag.; of those which followed I will only mention: Physical Causes of the Submergence and Emergence of Continents, Geol. Mag., 1874, p. 309; Schmick, Die Umsetzung der Meere und die Eiszeiten der Halbkugeln der Erde, ihre Ursachen und Perioden, 8vo, Köln, 1869; by the same, Das Fluthphänomen und sein Zusammenhang mit den säculären Schwankungen des Seespiegels, 8vo, Leipzig, 1874; by the same, Die

All explanations belonging to the group of gravitation theories presuppose that the sum of observations as to the oscillations in various parts of the world may, after the elimination of erroneous or doubtful cases, be expressed by some simple formula; in other words, that there exist great and continuous regions of changing level, the distribution of which is related to the rotation axis of the globe according to some easily recognizable law. If, on the other hand, it can be shown that the distribution of these oscillations is sporadic, not following any recognizable law, then their origin cannot be sought in alterations of the form of the sea, the whole group of gravitation theories must be abandoned, and we must return, in spite of all objections, to the theory of movements of the solid crust.

There is no lack of attempts to determine the geographical distribution of the so-called 'secular oscillations.' We may refer to the works of *Récluz*[1], *Peschel*[2], *Hahn*[3], *Issel*[4], and others; as well as to the little sketch-map by *G. R. Credner*[5].

These attempts have not led to results sufficiently uniform to come under the form of a law. All the authors just mentioned indicate elevations and subsidences in the most diverse geographical latitudes, often, indeed, opposite movements in the most closely adjacent regions.

The case is otherwise with the investigation made by *H. H. Howorth*. In a number of tracts which have appeared since the year 1871, he has attempted to show, always from the standpoint of the elevation theory, that the land round the poles is rising, and he finally reaches the conclusion that an actual deformation of the planet is in progress, contraction taking place about the equatorial region, and proceeding thence in an increasing convexity, which probably attains its maximum over the magnetic poles[6].

Aralo-Kaspi-Niederung und ihre Befunde im Lichte der Lehre von den säculären Schwankungen des Seespiegels und der Wärmezonen, 8vo, Leipzig, 1874. On the other side, in particular Pilar, Ein Beitrag zur Frage über die Ursachen der Eiszeiten, 8vo, Agram, 1876. As treatises all tending more or less in the direction of this branch of the gravitation theory I may also mention: Le Hon, Périodicité des déluges, 8vo, Bruxelles, 1858; Carret, Le déplacement polaire, preuves de la variation de l'axe terrestre, 8vo, Paris, 1876; Péroche, Les phénomènes glaciaires et torrides, causes auxquelles doivent être attribues la précession des équinoxes et les oscillations polaires, 8vo, Paris, 1877. On the other hand, A. Woeikof, Mitth. geogr. Ges. Wien, 1882, pp. 356–369, and Am. Journ. Science, 1886, XXXI, pp. 161–178.

[1] Récluz, La Terre, 3e éd., 1874, I, pp. 709–767; general map, pl. xxiv; also Revue des Deux Mondes, 1er janv. 1865.

[2] O. Peschel, Neue Probleme der vergleichenden Erdkunde, 2. Aufl., 1876, pp. 97–114.

[3] F. G. Hahn, Untersuchungen über das Aufsteigen und Sinken der Küsten, 8vo, Leipzig, 1879.

[4] A. Issel, Le oscillazioni lente del suolo o bradisismi, gr. 8vo, Genova, 1883.

[5] G. R. Credner, Die Deltas, ihre Morphologie, geographische Verbreitung und Entstehungsbedingungen; Peterm. Geogr. Mittheil., Ergänzungsbd. XII, 1878, pl. iii.

[6] Howorth's first statement that all the land round the north pole is rising, and *the nearer it lies to the pole the greater the extent of the elevation*, I find in Nature, Dec. 20,

Strange to say, Howorth does not seem to have observed that his results, if they should prove true, would at once menace the very foundation of the elevation theory, and would raise the question whether this uniform result is not to be ascribed to an alteration in the form of the surface of the sea. It must be admitted, besides, that Howorth's actual data are somewhat defective, and that many contradictory observations remain unexplained; on the other hand, we must not omit to mention that *Thomas Belt*, following another method based on a study of the existing distribution of species, has arrived quite independently at a result which, in substance, exactly corresponds with that obtained by Howorth [1], though it receives a very different explanation.

Belt maintains that a rising of the waters about the equator has been taking place since the glacial period. The difference between the marine Mollusca on the two sides of the isthmus of Panama; the resemblance between the terrestrial Mollusca of the northern islands and the West Indies as far as Puerto Rico and those of Central America and Mexico, and the correspondence of the land shells of the southern islands partly with those of Venezuela and partly with those of Guiana; the well-known facts of geographical distribution presented by the Malay archipelago, and the gigantic statues of Easter island, are for Belt so many proofs of this continuous rising. The author believes the explanation to lie in the periodic and simultaneous formation of ice-caps at both poles, as the result of changes in the obliquity of the ecliptic.

The contraction of the globe about the equator imagined by Howorth, and the rising of the oceans about the equator supposed by Belt, are, however, only two different explanations of one and the same conception of the facts.

This conception, however, is the same as that which long ago was held—though on different grounds—by Swedenborg and Frisi, and more recently by Robert Chambers. It presupposes on each side of the equator a nearly *symmetrical* and homologous arrangement of the regions of elevation and depression, while from the premises of Adhémar and his successors, the oscillations on the opposite sides of the equator must be opposed, i.e. *complementary*.

1871, pp. 162 and 163; much more detailed evidence is given for the statement in a work by the same author, Recent Elevations of the Earth's Surface in the Northern Circumpolar Regions, Journ. Geogr. Soc., 1873, vol. 43, pp. 240–263. The data for the South Polar regions are contained in Nature, March 28, 1872, pp. 420–422, and the conclusions drawn chiefly in Nature, Jan. 15, 1874, p. 201. Murphy maintains, op. cit. Jan. 18, 1872, p. 225, that the southern regions are also rising, so that the perimeter of the equator is diminishing; cf. also Hamilton, op. cit., Jan. 25, 1872, p. 242, and Murphy, Feb. 8, 1872, p. 285.

[1] T. Belt, The Naturalist in Nicaragua, 8vo, 1874, pp. 263–274. Also: The Glacial Period in the Southern Hemisphere, Quart. Journ. of Science, July, 1877.

Comtemporary literature shows that opinions on this important question are still widely divergent.

Howorth and Belt, as we have just seen, were led by different paths to the same view, that which involves a symmetrical displacement of masses of water on each side of the equator.

It may be shown that the opinion of many observers eminent in this branch of inquiry inclines towards the view represented by this last group of theories. I may mention, in particular, *Julius von Haast*[1], the most competent authority on the ancient terraces in New Zealand, and *Warren Upham*[2], who has described the recent alluvial land in New Hampshire. In 1875, *N. S. Shaler* declared the theories of Adhémar and Croll to be very improbable, since all observations are in favour of the simultaneous glaciation of both hemispheres, but he nevertheless expressed his conviction that it is the sea and not the land which is subject to movement[3].

The gravitation theory introduced by Adhémar, which involves the asymmetric accumulation of the seas, has nevertheless, in the completed form which we owe to Croll, found numerous adherents in England: it has been fully accepted by *Charles Darwin*, *James Geikie*, and many others; it is true that in most cases the theory has been applied to explain changes of climate rather than movements of the sea-level.

Charles Lyell, whose long career produced such important results for our science, was always a keen opponent of the theory of the elevation of volcanic mountains, the theory, that is, of elevation craters, and an equally keen and influential champion of the theory of secular oscillations of the continents. On the formation of mountain chains, he never expressed himself with equal decision. In the later editions of his 'Principles,' all the older theories and arguments in favour of continental movements are retained; but notwithstanding this, Croll's theory finds recognition as revealing a hitherto neglected *vera causa* of a certain oscillation of the sea-level[4].

The elevation theory rests, even at the present day, on the alleged unequal movement of neighbouring regions, and the alleged tilting movement of whole countries such as Sweden and Greenland. In spite of the

[1] J. v. Haast, Geology of the Provinces of Canterbury and Westland, New Zealand, 8vo, 1879, p. 381.

[2] Warren Upham in Hitchcock, Geology of New Hampshire, 8vo, 1878, III, p. 329 et seq.

[3] N. S. Shaler, Notes on some of the Phenomena of Elevation and Subsidence of the Continents; Proc. Boston Soc. Nat. Hist., 1875, XVII, pp. 288–292. A similar recognition of the return to the idea of the variability of the ocean surface is also to be found in certain hydrographic treatises, e. g. in Stahlberger, Ueber Seespiegelschwankungen, Mittheil. geogr. Ges. Wien, 1874, 2. Ser., VII, pp. 58–66.

[4] Lyell, Principles of Geology, 11th ed., 1872, I, p. 279. The introduction to this edition is the best illustration of Lyell's position with regard to this question. Croll's gravitation theory is recognized, but its influence on climate is not admitted to be so great as is claimed by other authors.

attacks of certain physicists, directed chiefly against the absence of a closer definition of the stupendous force, which is said to elevate and depress great parts of the earth's surface, the elevation theory has maintained its position as the accepted doctrine up to the present day, especially among geologists who devote themselves to stratigraphy; from this doctrine the explanation of transgressions and gaps in the series of formations is derived, just as it was sixty or seventy years ago[1].

Wrede's hypothesis that the position of the centre of gravity of the solid earth is altered by the displacement of sediments, was revived some time ago by *G. Jäger*[2].

H. Trautschold has drawn his conclusions from a comparison of the nature and distribution of the ancient sediments; in numerous treatises he has persistently maintained, in opposition to the prevailing opinion, that secular upward or downward movements of the continents do not take place[3].

This wide divergence of opinions on a question of vital importance in our science, has led me to submit all the actual observations hitherto obtained to a fresh examination. I felt the further incited to this task, because, relying on the teaching of revered masters, I myself made many years ago an attempt to bring the new views on the formation of mountains into harmony with the received doctrines; I refer to my treatise entitled 'Die Entstehung der Alpen.' I there maintained that the movement of Scandinavia might be attributed to the formation of a fold of great amplitude within the earth's crust. Still, although I added that the wide distribution of certain marine deposits, especially of the middle Cretaceous, is not to be explained in this way, and, at the same time, expressed my belief that the temporary extension of the seas must depend on causes far more general, and probably subject to a certain degree of periodicity; yet, even with these qualifications, I could not conceal from myself that such an interpretation was unsatisfactory[4].

The folding of the mountain chains and the formation of horizontal strand-lines which run without interruption over mountain segments of

[1] 'Again, successive strata of different kinds are accounted for by the subsidence of land; it sinks beneath the sea to receive its load of sediment, as the camel drops on its knees and then rises; but, more patient and accommodating than the camel, it takes as many loads as the geologist is pleased to impose on it. This assumption of the unlimited sinking and rising of land is plausible and convenient, but it is inexplicable and unproved.' Desborough Cooley, Physical Geography, 8vo, London, 1876, p. 428. Siemens expresses similar views in Monatsber. Akad. d. Wiss. Berlin, 1878, p. 572.

[2] G. Jäger, Die Polflüchtigkeit des Landes, Ausland, 1865, p. 867, and 1867, p. 121.

[3] H. Trautschold, Ueber säculäre Hebungen und Senkungen, 1869; Sur l'invariabilité du niveau des mers, 1879; Zur Frage über das Sinken des Meeresspiegels, 1880, and many later articles; all in the Bull. Soc. Imp. des Natural. de Moscou.

[4] Die Entstehung der Alpen, 1875, pp. 119, 150; Ueber die vermeintlichen säculären Schwankungen einzelner Theile der Erdoberfläche, Verhandl. geol. Reichsanst., 1880, pp. 171–180.

the most diverse description, are two entirely different things, and the elevation theory therefore ascribes to the lithosphere two movements of a completely different nature. An examination of the actual data on which this theory rests has proved, however, to be an extremely difficult task.

In 1834, at the annual meeting of the Geological Society of London, not long after the publication of the last volume of Lyell's 'Principles of Geology,' the president *Greenough* warned the members against too ready an adherence to the theory of elevation which was then rapidly gaining recognition. The statements regarding the elevation in Chili in 1822 were, he said, untrustworthy; the term 'elevation' was used in the most various senses, and of the uniform elevation of a whole continent it was almost impossible to form a conception; above all, a *terminology* was needed which should not involve any preconceived theory [1].

This warning appears to have produced no result, and it was not until 1848 that Robert Chambers introduced a new phrase; he spoke neither of elevation nor of subsidence, but only of 'changes of relative level,' or, as we shall say, *displacements of the strand-line.*

With the adoption of these neutral terms it at once follows that the displacements of the strand-line in an upward direction must be described as *positive,* those in a downward direction as *negative,* since this is the terminology universally employed by all oceanographers and in all operations of water gauging. Here we have no choice, and all investigators who have sought to abandon the adventurous sea of theories for the solid ground of fact, and have endeavoured to obtain information by direct measurements of the water-level from the shore, like Forssman for instance in his valuable investigation on the level of the Baltic, have adopted naturally the signs + and − in recording their results. In this work therefore the older term *elevation of the land* will be replaced by *negative displacement of the strand-line,* and *subsidence of the land* by *positive displacement of the strand-line.*

But if, equipped with this neutral terminology, we now attempt to proceed to a serious examination of the position, we find ourselves confronted with so many circumstances which may exert an influence on the sea-level, by so much uncertainty in the existing data, and by so many sources of error, that finally little remains as the result of many years' labour, but a conviction that many doctrines which in spite of the warnings of unprejudiced authorities have become accepted dogmas are erroneous, and a hope that the rising generation will succeed in obtaining a more exact knowledge of the laws which govern the statics of the seas. For this reason the following chapters in so far as they treat of displacement of the strand are mainly critical.

[1] G. B. Greenough, Address delivered at the Anniversary Meeting, Feb. 21, 1834; Proc. Geol. Soc., 1833–1838, II, pp. 54 et seq.

There are three methods of studying changes in the sea-level.

The first consists in tracing the various *extension of the ancient seas.* Although the strand-line itself can seldom be recognized, yet in the great transgressions, particularly that of the middle Cretaceous, we perceive the widely distributed signs of positive movement. Frequently, doubtless even as a rule, these transgressions are accompanied by erosion, and hence negative movements are far more difficult to discover by this method than positive, and are only rarely brought to light, if indeed they do not frequently escape observation altogether.

The second method is found in a comparative study of the *nature of the sedimentary formations.* Very distinguished investigators, Charles Darwin for example, have believed that sediments were only formed with a sinking sea-bottom, that is during a positive movement. This is by no means the case, but it is evident that with a predominance of the negative movement the approach of that critical moment is hastened when the upper surface of the sediment and the surface of the sea coincide at the same level. For the present it is sufficient to refer to what has been said with regard to the superposed and apposed series on the isthmus of Suez (I, pp. 378 et seq.).

The third method, finally, is the *examination of the existing coast,* but it is precisely in this study of the evidence furnished by marks upon the coast that we meet with the greatest difficulties. Positive movements as a rule conceal their own traces, and it is only exceptionally, as in the case of coral reefs, for instance, that they are definitely recorded. Negative movements leave visible signs: but this is not all. Even when an oscillatory movement is taking place, in which the positive character predominates, it may often happen that the only evidence which remains is that of a negative movement. An example will make this clear. Let *ab, bc, cd,* represent equal spaces traversed in equal times, and let us suppose that we have a preponderance of the positive movement, such that the ratio of the positive displacement to the negative is as 4 : 3. We shall then have the following scheme:—

		m		
e		$+lm$	$-mn$	
$+de$	$-ef$	$+kl$	$-no$	&c.
$+cd$	$-fg$	$+ik$	$-op$	$+pq$
$+bc$	$-gh$	$+hi$	p	
$+ab$	h			
a				

In 4 units of time the strand will traverse 4 positive units of distance from a to e, it will leave here its highest mark, and then sink through 3 negative units of time to h, it will then again ascend in 4 positive units of time to m, and so on. In this case, however, the relict strand-line at e

will remain visible through the 6 units of time included between *ef* and *kl*, of which 3 are negative and 3 positive, and it is only during the single unit of time *lm* that it will be concealed. Although the positive movement thus predominates in the ratio of 4:3, yet the chances are as 6:1 that a mark will be seen above the water-level from which negative movement may be inferred. Even in the case of a double predominance of the positive movement, that is with a ratio of 6:3, there is still a twofold probability that a negative mark will be seen above the water-level.

But in nature the movements do not take place either by regular oscillations or with regular intermittence; and a whole series of factors of greater or less importance come into play and influence the position of the strand. The simple example given above is intended merely to show how necessary it is not to lose sight of compensating movements.

In studying the strand we must further distinguish between the movements of the present day which may be directly recorded by tide gauges and those which can only be inferred from ancient remains such as the so-called 'raised beaches.' A link between the movements now in progress and those of the ancient world is afforded by evidence which lies within the limits of historic time, i.e. to which a date or period can be assigned and approximately expressed in figures, as for instance in the case of the *Lithodomus* borings in works of Roman construction.

It is obvious that the historic period, as we have defined it, is far from possessing the same importance and duration at the mouths of the Nile, of the Rhine, and the Mississippi; but similar differences also exist in speaking of other periods, as, for instance, the glacial or pre-glacial. Greenland is still in the glacial period, and no one who has seen the moraines of Lapland in the 70th degree of north latitude will find it easy to believe that these are just as ancient as those of the moraine lands long abandoned by the ice at the foot of the Alps.

One of the most dangerous sources of error lies, indeed, in the temptation to class together, without distinction, strand-lines of different age. Thus the oft-repeated assertion that Greenland is now undergoing a tilting movement rests solely on a mistaken association of extremely ancient high-lying strand-lines in the north with marks apparently positive on buildings in the south, which are of very recent date. It may, however, suffice to mention that in Ingalliko fjord itself, said to be experiencing a positive movement, high-level strand-lines are equally present, as in the north.

The level of the sea depends on the tides, the heat of the sun, the atmospheric pressure, the prevailing winds, the influx of fresh water, and, in enclosed seas, on evaporation. It is also affected by local sources of attraction and many other circumstances. Among these, however, are some which make it difficult to ascertain the mean level, and render a long

series of measurements necessary before changes of level can be made manifest; this is particularly true of the winds and climatic factors generally. Some movements, such as the tides, may be easily eliminated, owing to their periodicity; others, again, such as the attraction of the continents, only need be considered in the case of particular telluric changes; others, finally, such as the deposition of sediments, act slowly but constantly, producing a positive movement, which is general so far as it results from displacement, and local so far as it is a consequence of attraction. We shall have occasion later to study some of these factors in greater detail.

In addition to all these processes great and general negative movements are from time to time produced by the formation of fresh oceanic abysses, or by the addition of new areas of subsidence to abysses already in existence, and it is important to bear in mind that movements of this kind surpass all others in importance.

In the first volume of this work certain seas, in particular the Mediterranean, were studied in some detail; the various ages of successive subsidences in the Aegean, the North Atlantic, and the Tyrrhenian sea, were determined within narrow limits, and the relation of these seas to the older extensions of the Mediterranean were discussed. It is now my task to investigate the boundaries, first of the Pacific, and then of the Atlantic Ocean, and to compare them with each other, as a preliminary to the discussion of the great oceanic areas of subsidence. While thus engaged in a study of the coasts, opportunities will arise of completing the tectonic sketches which were outlined in the first volume, and so of preparing the way for the survey of the face of the earth, reserved for the last volume.

Although the formation of the Aegean inbreak falls possibly within a period more recent than the glacial episode, when the region was already inhabited by man, still we may fairly assert that a general subsidence of the strand-line, as a consequence of the sudden formation of a great oceanic abyss, has not taken place for some thousands of years past. Yet in contemplating those trifling changes in the coast-line, which take place here and there before our eyes—the results, as we have seen, of a great variety of circumstances—we are again and again tempted to regard them as the direct successors of those remote events which have left their traces in a long-forgotten past. Thus the displacements of the strand-line in the Baltic, at present a closed sea, have been interpreted as the effects of the same causes as gave rise to the ancient high-level strand-lines and shelly beaches of a sea which was certainly not thus closed.

It thus becomes necessary to subject some of the more important cases of change observed during the historic period to a searching examination. If, however, the result should lead us to the conclusion that local factors of

a climatic nature, for instance, possess a greater influence than is usually attributed to them, and that where these are absent long stretches of coast show no signs of movement within the historic period, yet this would not prove that such movement does not take place. A study of the animal kingdom does not reveal any change in species within the historic period, but it does not follow that species are immutable. All that we can conclude is that within the limits of observation and of the period over which our observations extend, such changes are not discernible. But this result would involve considerable modification in current views as regards the strand-line.

With the increased attention given during the last few years to the study of earthquakes and dislocations we have gained a closer acquaintance with the characters which distinguish a dislocation of the lithosphere, and at the same time have come to recognize the rarity of such an occurrence. The most remarkable dislocations of our times are no doubt those in the west of the United States, which have been described by Gilbert on the borders of the Great Salt lake, by Russell in the Great Basin, and by Reyer in the Sierra Nevada. These are all changes in the relative position of two segments of the earth's crust, occurring along a line which is usually many miles in length. The throw does not as a rule amount to more than a few metres; the course at the surface of the ground is always very sharply defined, often indeed it appears as an open cleft many miles long.

I know, however, of only a single case in which a recent dislocation has reached the sea-coast and produced a local change in the strand-line. This occurred in New Zealand: Lyell has given an account of it[1].

In the year 1848, during an earthquake at White Bluff, Cloudy bay, a fissure opened on the south coast of Cook strait, and ran to the south-south-west, parallel to the course of the mountains; it was said to be traceable into the interior for a distance of 60 miles. On January 23, 1855, a violent earthquake again occurred, and this time a line of dislocation appeared on the north coast of Cook strait; it began on the east side of Muka-Muka cliff, 12 miles south-east of Wellington, and was continued in a north-north-easterly direction, following closely the eastern foot of the Remutaka chain; it presented, for the greater part of its course, the form of an open fissure, and extended 90 miles into the interior of North island. This fracture may perhaps be regarded as the continuation of that which was formed in 1848 in South island. The area lying to the east of this line remained wholly unaffected by the fault of 1855; that to the west was displaced, downwards in South island, and

[1] C. Lyell, Bull. soc. géol. de Fr., 1865, 3e sér., XIII, pp. 661–667; Principles of Geology, 11th ed., 1872, pp. 82–89; also R. Mallet, Report on the Facts and Theory of Earthquake Phenomena, Rep. Brit. Ass., 1858, p. 105.

upwards in North island. In the south the subsidence close to the fissure amounted to 5 feet, in the north the elevation at its maximum, on the east side of Muka-Muka cliff, was 9 feet: a white band of nullipores which marked the former strand now stood, west of the line of dislocation, 9 feet above the water-level, while to the east its position remained unchanged.

From here the movement decreased towards the west, so that at Port Nicholson, 11 miles to the west, it was reduced to one-half, and at a distance of 23 miles was no longer observed. In this case we may speak of a tilting movement, for the dislocation is visible not only on the coast but in the interior of the island, and the facts are beyond doubt. The presence of a visible line of dislocation sharply separating the moved area from the unmoved distinguishes this case from all the others which we are about to discuss.

The method we shall adopt in this discussion is as follows:—

We shall first explain the structure of the shores of the Atlantic and of the Pacific Oceans, and then point out the very remarkable contrast which distinguishes these two ocean-basins.

We shall next pass on to consider the seas of ancient times. It must not be forgotten that it was the extraordinary extent of the seas in the earlier periods of the earth's history which gave the first impulse to all these discussions. The question will then arise whether the nature and the distribution of the ancient sediments point to local or general alterations in the sea-level. For the solution of this it will not be necessary to treat the deposits of each stratified system with equal fullness. On the contrary, I do not propose to discuss the distribution of the sediments in any detail except in those cases where observations have already led to clear and definite results, and I shall only incidentally refer to their nature. Thus in the Carboniferous the presence of the Coal-measures, so far as they bear on the question before us, will be taken into consideration, and in the Rhaetic period the formation of the limestones.

Among the events of the immediate past and of the existing present are some of exceptional importance, such as the origin of the Norwegian strand-lines, the behaviour of the Baltic, and the temple of Serapis at Puzzuoli in the Mediterranean; these demand a more detailed investigation. In conclusion we shall attempt a survey of existing observations.

CHAPTER II

THE OUTLINES OF THE ATLANTIC OCEAN

The Canadian shield. The Baltic shield. Glint lines. The table-land of Spitzbergen. Greenland. The Caledonian mountains. The Armorican mountains. The Variscian mountains. The syntaxis of Central Europe. The Iberian Meseta. Survey of the pre-Permian mountains in Europe. The islands of Europe. Western Africa. The east of Central and South America. Survey of the outlines of the Atlantic.

The Canadian Shield. The whole of the north-east of America, from the mouth of the St. Lawrence to that of the Mackenzie, together with the adjacent islands of the Arctic Ocean, belongs to a broad table-land of horizontal Palaeozoic beds, from beneath which the Archaean foundation crops out in the middle of the table-land not unlike a flat shield. This Archaean shield is thus surrounded by a ring of horizontally stratified sediments. The primaeval rocks composing it were not only folded in pre-Cambrian times, but were also exposed to severe denudation, so that the Palaeozoic series rests on the planed-down edges of Archaean folds. Many great patches of the Palaeozoic covering, however, remain preserved on the shield itself. The exposure of the shield, the outlines of the inner margin of its Palaeozoic girdle, as well as of the superincumbent Palaeozoic patches, result to a great extent from the glacial erosion which these regions have experienced in comparatively recent times.

It is to the exposed Archaean surface that we give the name of the Canadian shield.

Resting upon this shield, a little outside the central region towards the east, lies the sheet of water known as *Hudson bay.* As we might expect from the uniform structure of the land, this large arm of the sea is of a very uniform and trifling depth, which amounts, in Hudson bay and James bay, to only about 70 fathoms; towards Hudson strait, the bottom sinks to 100 fathoms and over; in Fox channel the depths are much more considerable. Hudson bay cannot, therefore, be compared with the deep inbreaks of the Mediterranean, the gulf of Mexico, or the Caribbean sea. Neither the expression 'fore-sea' (Vormeer) nor 'back-sea' (Rückmeer) is here applicable; the bay is only a submerged plateau, a shallow pan.

A similar structure is presented elsewhere in only one instance, that of the Baltic sea.

Such details as we possess concerning the structure of the neighbourhood of Hudson bay, and of the several Palaeozoic patches which rest upon the

shield, we owe almost exclusively to the labours of Robert Bell[1]. The shores are flat; only on the east coast of James bay and to the north of it, towards cape Wolstenholme, do more considerable heights occur, attaining nearly 2,000 feet.

A band of horizontally stratified sediments of Silurian and Devonian age starts from the south and extends for a great distance up to the southern and western part of the shores of James bay. On the west of Hudson bay, near the mouth of the Churchill river, lies a great mass of ancient quartzites with horizontal stratification. In the north crystalline schists are found about Chesterfield inlet; Marble island owes its name to an error; it is not formed of marble, but of quartzite and schist. At cape Southampton and on Mansfield island thinly stratified fossiliferous limestone of Silurian age lies in hundreds of horizontal beds, which the undermining waves break up into towers and pillars. The contrast between the plateau-like Mansfield island and the surrounding country is described as striking in the extreme. Between these regions the greater part of the land consists in all probability of gneiss. Cape Wolstenholme is also formed of gneiss, as well as a large part of the east coast, but in Natapuka sound remains of the Palaeozoic covering occur.

We will now pass out of the bay through Hudson strait, where the border of the shield is least known and where its form appears to be least regular.

The islands off cape Wolstenholme, Digges, Nottingham, and Charles island, as well as Prince of Wales sound and North bay lying opposite, on the coast of Meta incognita, are wholly composed of gneiss, as is all that is known of the south coast of Meta incognita as far as the Savage islands, near Resolution island.

Proceeding towards cape Chudley and the sea, however, we encounter an independent and fairly lofty chain, which can no longer be regarded as belonging to the Canadian shield or to its border. The position of this, as we shall see later, is of particular importance: it begins near Belle Isle straits and forms the whole coast of Labrador; in its northern part it attains a height of 6,000 feet and reaches Hudson strait near cape Chudley with a height of 1,500 feet. According to Bell's observations this coastal chain is not broad, and is followed on the west by a flat country through which the Whale river flows to the north into Ungava bay. In the south the two little islands, Castle island and Henley island, facing the northern point of

[1] R. Bell, Report on Hudson's Bay and some of the Lakes and Rivers lying to the West of it, Geol. Surv. Canada, Report for 1878–1880, p. 27, C. et seq.; by the same, Report on the Geology, Mineralogy, Zoology, and Botany of the Coast of Labrador, Hudson's Straits, and Hudson's Bay, op. cit. for 1882–1884, DD. Digges, near cape Wolstenholme, is only a single island cut through by two deep furrows; it was at one time supposed that three independent islands existed here.

Newfoundland, consist of horizontal sheets of an eruptive rock such as are known in several places elsewhere in Canada, intercalated into the lowest Palaeozoic beds, and these sheets form a startling contrast to the surrounding country, which consists of gneiss. We may add at once that the island of Anticosti in the gulf of St. Lawrence is formed of flat-lying Silurian beds.

The coast-chain of Labrador consists, so far as it is known, of gneiss and other Archaean rocks. Its lower parts are rounded by ice, but above it is broken up into jagged peaks and sharp ridges. The ice did not reach the upper parts, although in the south it extended up the slopes to a height of about 1,600 feet.

Sutherland had already shown that the highly glaciated west coast of Davis strait and Baffin bay, from Cumberland bay nearly as far as cape Walter Bathurst, consists chiefly of Archaean rocks; traces of a Palaeozoic covering have only been met with near cape Durban and to the south of it[1]. Hall subsequently visited the southern part of these regions: the most detailed observations have been made by Boas. From these it appears that a high and narrow coast-chain, precisely similar to that of Labrador, exists here. Dr. Boas has had the kindness to furnish me with the following description: 'The narrow range which forms Cumberland peninsula runs along the west coast of Baffin bay up to Lancaster sound. In Home bay, where the coast assumes a north to south direction, a remarkable gap occurs, and the hilly country of the west advances as far as Davis strait. This range, as far as it is known to me, consists in its central part of gneiss, in the peripheral parts of coarse-grained granites. The whole range, rising in steep horns and peaks to a height of 2,000 meters and over, is characterized by narrow valleys with precipitous walls which extend across the peninsula and connect the corresponding fjords of the opposite coasts, the height of the passes being scarcely 150 meters. The country is thus cut up into steep-walled mountain masses, three of which succeed each other as far as Home bay. Further to the north also the mountains are completely intersected by deep fjords which merge into valleys opening on to the western plains. Precisely analogous features are met with in the extreme north, where Hayes sound appears to form a similar divisional line, and where the valley which connects Greeley and Archer fjords separates two mighty highlands.

'To the west of the range lies a hilly country, apparently quite irregular, and composed of coarse-grained granite. A glance at the fjords of the north-west coast of Cumberland shows the predominance of a north-west and north to south direction in the course of the valleys. The form of the fjords is here very striking: they consist almost everywhere of basins connected by narrow gullies in which rapids are formed by the water flowing into or out of them according to the state of the tide.

[1] P. C. Sutherland, On the Geological and Glacial Phenomena of the Coasts of Davis Strait and Baffin's Bay; Quart. Journ. Geol. Soc., 1853, IX, p. 299.

'As we advance towards the west the hills become lower and the valleys broaden until we find ourselves at last on a boundless plain.

'Here the Silurian limestones begin, which in the more southerly parts of the country had been found at the upper end of Frobisher bay and on the shores of lake Kennedy, where they are surprisingly rich in fossils. The first of these localities was made known by Hall. Unfortunately I did not find the rock in place, since the plains were covered by very deep snow, so that I cannot say whether the beds lie horizontal or not; probably they do. The lakes of this region must certainly be regarded as relics of the sea. The whole eastern half of Fox basin is flat, and the plain is an exposed sea bottom, as is proved by the remains of whales, walruses, &c.

'Orographically, the peninsula bounded by Cumberland sound and Frobisher bay is completely separated from the range described above. The peninsula attains its greatest height in its southern parts, and slopes away to the plain towards the north-west. The northern shore consists exclusively of granite: in the south limestones (Silurian?) occur. Sandstone also has been found in the extreme south.

'The peninsula of Meta incognita is also completely independent of the northern plateau, for the plain reaches as far as Frobisher bay.'

I have given this information in full, since it embodies all that we actually know of a lofty and independent range; consisting chiefly of gneiss and extending from the southern part of Cumberland nearly as far north as cape Walter Bathurst. It is either the direct continuation of the lofty gneiss range, which Robert Bell followed along the coast of Labrador from Belle Isle strait to cape Chudleigh, or at least corresponds very closely in position with such a continuation.

To the west of this coastal range lies a flat country, in which Silurian limestone with horizontal stratification has been observed in several localities. Boas conjectures, with great probability, that the horizontal Silurian limestone which we shall meet with later more to the north in Prince Regent inlet is continued thence on to the flat eastern half of Melville peninsula, where Hall observed it near Igluling, thence to lake Nettilling (lake Kennedy) and to the upper end of Frobisher bay[1]. Such then is the north-eastern border of the Canadian shield, separated by a long and lofty gneiss range from the depths of Baffin bay and Davis strait.

A continuation of this Silurian zone is so far not known on the shores of Hudson strait, and it is therefore not possible to say whether it should be looked for in the plain which extends from Ungava bay through Labrador southwards to Belle Isle strait and the island of Anticosti.

That Anticosti consists of horizontal Silurian limestone has already been

[1] Franz Boas, Baffin-Land; Geographische Ergebnisse einer 1883 und 1884 ausgeführten Forschungsreise: Peterm. Mittheil., Ergänzungsheft No. 80, 1885, pp. 50 and 57.

mentioned; but just as to the north-east the Silurian girdle in Cumberland peninsula is bounded on the exterior by the lofty gneiss range of the coast, so on the St. Lawrence it is bounded on the exterior by the folded mass of Maine and New Brunswick.

The east of the United States is traversed by folds which have been produced by a tangential movement directed from the existing Atlantic ocean towards the mainland. We have seen (I. pp. 553–555) that from Alabama to Georgia these folds strike to the north-east more or less parallel with the coast, thus forming the Alleghany mountains, and are finally continued into the Catskill mountains north-north-west of New York, where they are joined by a system of folds striking from north to south.

The Alleghanies are not separated from the adjacent plain on the west; the intensity of the folding decreases in this direction and a secondary folded formation or parma, the Cincinnati uplift, lies in front of them. With the folds which run from north to south the case is different. Their western border extends along the length of lake Champlain, reaches the St. Lawrence near Quebec, and then, with the trend curving to the north-east, follows the right shore of this great river. The country to the right of the river is folded, that to the left of it is flat table-land.

It is true that on the left shore the whole Archaean and Azoic series has been intensely folded, but it was abraded at a very early period, and on the denuded folds several members of the Silurian were deposited horizontally; these, however, have been so far removed in later times, that over large areas the Archaean foundation alone is visible. This is the case according to Laflamme around lake St. John and in the whole fluvial region of the Saguenay. Some parts of the Palaeozoic patches of lake St. John contain petroleum[1].

Selwyn's admirable account of the structure of this region confirms Logan's view, that the St. Lawrence must be regarded as marking an extremely important boundary line in the structure of the country[2]. All the Silurian on the right bank, from Quebec away towards cape Rozier, follows the trend of the shore-line and is overfolded towards the west, so that the beds are inverted as in the outer border of the Alps. These Silurian folds are followed towards the east, at a distance of a few miles from the river, by a long and narrow but not continuous zone of Archaean rocks; two other similar zones, running close together and nearly parallel, strike north and south towards the south-east part of Chaleur bay; another zone

[1] J. C. K. Laflamme, Report on Geological Observations in the Region of the Saguenay; Geol. Surv. Canada, Report for 1882–1884, D.

[2] A. Selwyn and G. M. Dawson, Descriptive Sketch of the Physical Geography and Geology of the Dominion of Canada, 8vo, Montreal, 1884, with map, pp. 5–26; also E. Gilpin, jun., The Geology of Cape Breton Island, Nova Scotia, Quart. Journ. Geol. Soc., 1886, XLII, pp. 515–526, map.

of Archaean masses runs in a curved line along the bay of Fundy, then reaches the most northerly part of cape Breton on the north-east and is continued across the sea into Newfoundland. Still further to the east follow the zones directed to the east-north-east which have been already mentioned (I. p. 554).

The folding is older than a part of the Carboniferous period, as is shown by the lie of the Coal-measures in New Brunswick, and did not extend beyond the present line of the lower St. Lawrence, but it has been dammed back against this line, and overfolding has taken place in consequence. Selwyn represents the structure of the St. Lawrence valley itself by the accompanying section.

On the left we see the edge of the table-land; an upper member of the lower Silurian (Trenton limestone) lies in transgression on the abraded

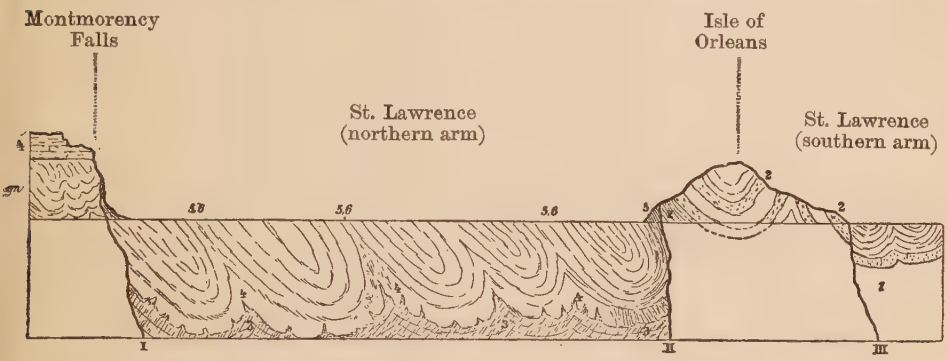


FIG. 3. *Hypothetical Section across the river St. Lawrence and the isle of Orleans.* After Selwyn.

I, II, III Faults; *gn* Gneiss; *1* red, green, and black shales and sandstones with Cambrian fossils in the included pebbles ('Lauzon stage'); *2* Levis conglomerate and Graptolite shales (Lower Silurian); *3* Chazy limestone and other beds (Lower Silurian); *4* Trenton limestone, lying transgressively on the gneiss (Upper Silurian); *5, 6* Utica and Hudson stages (Upper Silurian).

folds of the gneiss. The northern arm of the St. Lawrence is a true fault trough, for the downthrown strata of the river bed, visible along the fractures on both shores, belong to the more recent divisions of the lower Silurian (Utica and Hudson stages); the isle of Orleans is a horst, and at the same time part of the folded region.

The boundary between the folded region and the table-land runs between cape Rozier and the island of Anticosti; this part of the gulf of St. Lawrence and the lower part of the river is therefore a true 'fore-valley' (Vorthal), like the Persian gulf.

The folds of New Brunswick and cape Breton island run out in jagged ends towards the gulf of St. Lawrence, and are continued, as we said above, into Newfoundland. The very first examination of the island made by Jukes in the years 1839 and 1840, showed that its outline is entirely determined by folds striking across it; the saddles of these folds form peninsulas

both on the north and south coasts, while the bays, such as White bay, Notre Dame, Bonavista, Trinity and Conception bay in the north, and Fortune, Placentia and St. Mary bay in the south, correspond, for the greater part, to synclinals. The later surveys of Murray and Howley confirm this result; the great northern peninsula is probably a single continuous anticlinal; a fault appears to run with the strike from the neighbourhood of cape Ray in the south-west of the island through the Grand lake to White bay, that is, across the whole island: in the south-east, the extent to which the outline is determined by the folds is shown with particular clearness by the Avalon peninsula. The mean direction of the folds is N. 27° E. They are formed of Archaean and Palaeozoic rocks; the Carboniferous formation, or at least a part of it, lies unconformably upon them [1].

Here we have before us a striking example of that form of coast which, with F. von Richthofen, we will term the *rias* coast. It indicates the plunging of great folded mountains beneath the ocean [2]. Thus, the outer border of the girdle of flat-lying beds surrounding the Canadian shield is defined towards the north-east by the gneiss mountains of the west coast, by Baffin bay, Davis strait, and Labrador; towards the south-east by the St. Lawrence, and the folded mountains of New Brunswick and Newfoundland. On the south and west there is no such outer boundary of the encircling zone; it becomes continuous, in Michigan, Wisconsin, Minnesota and the northern Prairie land, with the widely extended Palaeozoic deposits of the neighbouring regions, and is covered towards the west by the transgressive Cretaceous.

On the inner border of the girdle, that is, along the margin of the Archaean shield, a phenomenon appears for the first time to which I shall subsequently have frequent occasion to refer; I allude to the evident connexion which exists between the position of the great lakes and the course of this boundary line.

The line runs from the north-east end of lake Ontario to the east end of Georgian bay, and thence towards the west end of lake Superior. The northern shores of the great sheet of water consist chiefly of Archaean, or at least Azoic rocks, while on the south side the various members of the Palaeozoic series occur, and spread out towards the United States.

Further to the north-west, the coincidence of the lakes with the boundary of the Archaean shield is still more striking; Richardson, Isbister, and other observers long ago called attention to it [3].

[1] J. B. Jukes, General Report of the Geological Survey of Newfoundland, 8vo, London, 1843, map, p. 128 et seq.; A. Murray and J. P. Howley, Geological Survey of Newfoundland, 8vo, London, 1881, p. 139 et passim; also J. Milne, Notes on the Physical Nature and Mineralogy of Newfoundland, Quart. Journ. Geol. Soc., 1874, XXX, pp. 722–745.

[2] F. von Richthofen, Führer für Forschungsreisende, 8vo, 1886, p. 308.

[3] J. Richardson, On some Points of the Physical Geography of North America in connexion with its Geological Structure, Quart. Journ. Geol. Soc., 1851, VII, pp. 212–215;

The east side of lake Winnipeg is Archaean, while the islands and the west shore belong to the horizontally stratified Palaeozoic border; on this border lie Winnipegosis, Manitoba, and a crowd of smaller sheets of water, and to the west of these begins that vast region of Cretaceous deposits which extends to the foot of the Rocky mountains (I, pp. 558, 584).

In descending the river Athabasca, Bell found himself between Cretaceous rocks as far as Drowned rapid, i.e. to about lat. 56° 40′ N.; from this point onwards Devonian sandstone, rich in petroleum and lying horizontal, makes its appearance. The petroleum forces its way up through the Cretaceous beds, flows out and covers the slopes of the shores with bitumen. The outflow, however, appears to be very local; a thick bed of clay at the base of the Cretaceous holds the petroleum down over large areas. Some patches of Cretaceous are still to be seen further to the north; the flat-lying Palaeozoic deposits are continued to lake Athabasca and form its southern shore as far as it is known. The northern shore, on the other hand, consists of gneiss. Gneiss also forms the islands at the west end of the lake and the country about the mouth of the river Athabasca, and the exit of the Great Slave river[1].

The work of the Geological Survey of Canada, which has extended as far as the Great Slave lake, and the highly important explorations of Richardson, Youle Hind, Kennicott, and others, in the inhospitable regions which stretch northwards from the Great Slave lake to the Arctic Ocean, enable us to trace the boundary between the Archaean shield and the Palaeozoic border, which takes approximately the following course[2]:—

For a very long distance it almost coincides with the Slave river; and that half of the Great Slave lake which lies east of the mouth of this river is floored by Archaean rocks, that to the west, on the other hand, by Palaeozoic beds. On the west shore important springs of petroleum occur. To the north of the Great Slave lake the boundary is indicated, according to Richardson, first by a long arm of the lake, then by a series of smaller sheets of water. It extends to lake La Martre, then with a change of direction reaches the south-east part of Great Bear lake in MacTavish bay, and follows the lower course of the Coppermine river down to the sea,

by the same, Narrative of an Arctic Search Expedition, 2 vols., London, 1851, and The Polar Regions, Edinburgh, 1861, pp. 285–289; Murchison, Siluria, 4th ed., 1867, p. 440 et passim; further, A. K. Isbister, On the Geology of the Hudson Bay Territories and of portions of the Arctic and North-western Regions of America, Quart. Journ. Geol. Soc., 1855, XI, p. 503. This western boundary of the shield from the south up to the Slave lake is marked on the general map of the Geological Survey of Canada which appeared in 1883.

[1] R. Bell, Report on Part of the Basin of the Athabasca River, N.W. Territory; Geol. Surv. Canada, Report for 1882–1884, CC.

[2] F. B. Meek, Remarks on the Geology of the Valley of Mackenzie River, with Figures and Descriptions of Fossils from that Region, chiefly collected by the late R. Kennicott; Trans. Chic. Acad. Sci., 1867–1869, I, pp. 61–114, pl.

so that cape Barrow and its adjacent islands in Coronation gulf consist of granite and gneiss, while cape Krusenstern, a little further west, belongs to the Palaeozoic girdle, which, maintaining a great breadth, extends beyond the mouth of the Mackenzie.

Those explorers who have followed the course of the Mackenzie have thus encountered only Palaeozoic deposits and some patches of upper Cretaceous and Tertiary; but we have already mentioned that from the upper tributaries of the Peace river the border of the Rocky mountains assumes an almost north-and-south direction, so that it should meet the Mackenzie below the confluence of the Liard (I, p. 558), and indeed, steeply upturned beds, offering a striking contrast to the horizontal strata of the rest of the broad border, have been observed at several localities within this region, particularly below Fort Simpson, that is to say a little below the confluence of the Liard and the Mackenzie, and the heights visible from there have, in fact, been expressly described as spurs of the Rocky mountains. Then follows on the Mackenzie river a long stretch of country formed of horizontal Palaeozoic beds; near the Ramparts, however, in lat. 66° N. a steep dip to the north-west predominates, but still further down the valley, in the narrows above the delta, the beds again become horizontal; to the east they are known as far as the upper course of Anderson river, or indeed, as we saw above, even as far as cape Krusenstern, and to the west as far as the upper reaches of Porcupine river. Kennicott, MacFarlane, and Petitot have traced them in these remote regions[1].

Some connexion with the Rocky mountains thus evidently exists, though its precise nature is not known. A very remarkable fact, established by Meek, is the extraordinary constancy and importance presented by the middle divisions of the Devonian within the Palaeozoic border. The fossils which have been found in it enable us in fact to trace the deposits of the Hamilton group (middle Devonian) from Rock island, Illinois, through Iowa, Minnesota, Dakota, the great girdle along the lakes, and down the Mackenzie almost to the Arctic Ocean; the fossiliferous localities most remote from one another, separated by nearly thirty degrees of latitude, possess a not inconsiderable number of species in common; in the south, as well as at several localities in the extreme north, these deposits are characterized by their richness in petroleum and by salt springs; this character extends, indeed, as far east as Gaspé, and we have already mentioned it in connexion with the isolated patches of lake St. John, north of the lower St. Lawrence.

As regards more recent deposits a number of patches may be observed on the Bear river, which flows from the Great Bear lake into the Mackenzie.

[1] Meek, tom. cit., p. 74 et seq.; Hébert, Documents sur la géologie du MacKenzie, recueillis par le Père Petitot, Bull. Soc. géol. de Fr., 1874-1875, 3e sér., III, p. 87; Petitot, Notes géologiques sur le bassin du MacKenzie, tom. cit., pp. 88-93.

Sir John Richardson found an Ammonite in the rapids of this river; Hind brought home an Ammonite and an Inoceramus, obtained from horizontal beds. The marine Cretaceous beds thus extend along the outer border of the Rocky mountains from the far-distant south to lat. 65° N. Tertiary lignites appear in many places, both on the Bear river and the Mackenzie; the plant remains have been described by Heer. They extend as far as the islands which lie opposite the mouth of the Mackenzie; one patch lies between cape Bathurst and cape Parry; it was this patch that Miertsching saw on fire in 1850. From here the lignites extend further to the west coast of Banks' Land and Prince Patrick island [1]. The phonolite mountains of the lower Mackenzie and of the Bear river, mentioned by Petitot, are probably of the same age.

We thus perceive that the abraded Archaean platform, on which Hudson bay lies, may be traced from the east to a great girdle of lakes, the position of which stands in evident connexion with the course of the flatly-bedded Palaeozoic border. For, apart from the isolated patches of Palaeozoic resting upon it, already mentioned as occurring on the shores of Hudson bay, the boundary of the Archaean region runs in such a manner that the north coast of the northern bays of lake Huron, the north coast of lake Superior, and the east coast of lake Winnipeg still consist of Archaean rocks, while the sheets of water themselves lie entirely or for the greater part on the Palaeozoic girdle; and from lake Winnipeg the boundary runs through the western end of lake Athabasca across the Great Slave lake, following the great notch in its north side near Fort Rea, through lake La Martre, through the east half of the Great Bear lake, and finally to Coronation gulf in the Arctic Ocean.

Isbister long ago pointed out the analogy between the position of Coronation gulf and of the lakes just discussed. In order to examine more closely into this resemblance, let us now turn to the Arctic archipelago.

Among the many perilous journeys made through the Arctic archipelago of North America, none has produced richer results, as regards our knowledge of the geological structure of this region, than the search for the remains of Sir John Franklin and his companions, conducted by M'Clintock in the years 1857 to 1859. It was the results of this expedition that Haughton made use of, in conjunction with other observations of an earlier date, when he constructed the first general map of the region, and clearly displayed the extremely simple manner in which its stratified rocks are arranged [2].

[1] O. Heer, Flora fossilis arctica, 1868, I, pp. 25 and 135–139.

[2] Capt. F. L. M'Clintock, Reminiscences of Arctic Ice Travel in Search of Sir J. Franklin and his Companions, with geological Notes and Illustrations by S. Haughton, Journ. Roy. Dub. Soc., 1858, I, pp. 183–250, pl. and geological map; by the same, The Voyage of the

All these islands and peninsulas, from the continent of America to the north of Parry islands, form the horizontally stratified northern border of the great Archaean shield which we have just studied in the north of the continent: the several sedimentary formations of this border are so arranged that they strike to the east or north-east, and become progressively more recent as they are traced towards the pole [1].

The Archaean rocks, which form cape Barrow and the adjacent islands

FIG. 4. *Arctic North America* (after Maclure, Haughton, and others).

A Archaean and granite; *s* Silurian; *cu* Devonian (?) and basal Carboniferous; *ca* Carboniferous limestone; *m* Trias (?) and Jurassic; *te* Leaf-bearing Tertiary beds (cape Bathurst, north-west Banks' Land and Prince Patrick island); Basalt on cape Alexander in Smith sound.

in Coronation gulf, are also met with at the mouth of the Great Fish river; Rae observed them on Melville peninsula, and their northern margin passing through Eclipse sound reaches the shore of Baffin bay near cape

Fox in the Arctic Seas—A Narrative of the Discovery of the Fate of Sir J. Franklin and his Companions, 8vo, 1859; Append. No. IV, Geological Account of the Arctic Archipelago, by S. Haughton, pp. 372–399, and geological map; general descriptions also in O. Heer, Flora fossilis arctica, I, 4to, 1868, map; C. E. de Rance, Arctic Geology, Nature, 1875, p. 448, geological sketch-map. The most important works are cited by R. Jones, Manual of the Natural History, Geology and Physics of Greenland and the neighbouring regions, 8vo, 1875, London.

[1] A new map of the Arctic regions by G. M. Dawson appeared in 1883, too late to be made use of here. It does not render necessary any important alteration of our general description, but extends the Silurian, for example, over Wollaston Land and Victoria Land; G. M. Dawson, Notes to accompany a Geological Map of the Northern Portion of the Dominion of Canada, Geol. Surv. Canada, 1887 (Annual Report for 1886), R, 62 pp. and map.

Walter Bathurst. To the north of this cape, the eastern part of North Devon as far as cape Warrender consists of the same rocks.

In these regions, especially near cape Walter Bathurst, as well as in Wolstenholme sound on the east side of Baffin bay, the ancient rocks are overlaid by red sandstone, which is, perhaps, the same sandstone as that visible towards the west, in North Somerset, as the base or lowest member of the Silurian deposits.

The Archaean region is followed by a broad girdle of Silurian, which, in continuation of the broad Palaeozoic region already mentioned as lying between cape Krusenstern and the mouth of the Mackenzie, extends from Coronation gulf to Baffin bay. This zone consists of alternating beds of limestone and argillaceous sediments: their horizontal stratification gives to the cliffs that resemblance to fortifications so often mentioned by Arctic explorers.

With regard to Wollaston Land and Victoria Land I possess no information. The Silurian zone is known in the southern part of Banks' Land, and it forms the northern half of Prince Albert Land; it includes Prince of Wales Land, the little islands in Barrow strait, the greater part of Cornwallis island and of North Devon up to Jones sound, then both shores of Lancaster sound and of Prince Regent inlet, North Somerset, and to the south the greater part of Boothia with the magnetic pole, and King William Land[1].

In Peel sound the Archaean or more recent granitic rocks are visible on the coast beneath the Silurian: cape M'Clure on Prince of Wales Land is described as eruptive syenite.

It is very remarkable, considering the great development of Devonian sediments in the valley of the Mackenzie, that only isolated traces of a Devonian zone have been met with in the Arctic archipelago, as, for instance, on the Princess Royal islands and Byam Martin.

The next zone is formed mainly of sandstone, and in some localities contains coal beds. Heer, judging by the position of the beds and the plant remains, assigns it to the lower Carboniferous and the Ursa stage[2]. It forms the north half of Banks' Land, the south half of Eglinton, Melville island with the exception of the two northern peninsulas, Byam Martin, next Bathurst, with the exception of the three northern peninsulas, and is then, perhaps, continued across North Devon to the small islands which lie to the east.

This coal-bearing zone is followed in normal superposition by a richly fossiliferous zone of marine Carboniferous limestone. It comprises Prince

[1] The most important source of information previous to M'Clintock on the Silurian fauna of this zone is J. W. Salter, On Arctic Silurian Fossils; Quart. Journ. Geol. Soc., 1853, IX, pp. 312–317, pl.

[2] Heer, Flora fossilis arctica, I, p. 19, et passim.

Patrick island, the northern part of Eglinton, all the northern promontories of Melville and Bathurst, the little islands of Penny strait and Grinnell Land [1].

The Carboniferous limestone is the northernmost zone; but in the east of Prince Patrick island, on the north-west coast of Bathurst and on several little islands north of Grinnell Land, small patches of later deposits rest upon it, and indicate a Mesozoic zone lying beneath the Arctic Ocean. The fossils consist of the remains of Saurians, Ammonites, and a few bivalves. Neumayr has compared the remains of Ammonites from Wilkie point, Prince Patrick island (lat. 76° 20′ N.), with species of the middle Jurassic [2].

Since the parallel zones just enumerated strike east-north-east or north-east, the question arises whether they do not reappear on the western shores of Smith sound or of Kennedy channel. The structure of these coasts, as represented by Feilden and de Rance, certainly shows that here also Archaean, Silurian, and Carboniferous rocks are present, and that here too a north-easterly strike predominates, but the beds are upturned and folded, and we thus enter a region of fundamentally different structure [3].

We will only cast a hasty glance over these regions.

The Archaean rocks of Ponds inlet, cape Walter Bathurst, and eastern North Devon form towards the north the whole of the lofty coast of Ellesmere Land, and near cape Isabella they cross over to the east side of Smith channel, where they are covered by leaf-bearing Tertiary beds in the vicinity of port Foulke.

Silurian deposits reach the coast with a north-east strike, and occupy almost the whole area lying between lat. 79° and 80° N. On Bache island they lie fairly flat on the syenite and granite foundation, but in Norman Lockyer island in lat. 79° 25′ N. the dip becomes steeper, and further on an anticlinal is formed. This Silurian zone, which terminates on the west side of Smith sound in Scoresby bay, is continued with the same strike obliquely across this arm of the sea, and on its east side forms in all probability a great part of the floor of the Humboldt glacier and of Washington Land. It also embraces Petermann fjord, Polaris bay, and the interior of Hall's Land as far as Newman bay.

North of the Silurian region follow strongly folded ancient rocks, mica

[1] The Grinnell Land of certain travellers, separated from North Devon only by Arthur straits, and not to be confounded with Grinnell Land in lat. 80° N. on the Kennedy channel.

[2] M. Neumayr, Die geographische Verbreitung der Juraformation; Denkschr. k. Akad. Wissensch. Wien, 1885, L, pp. 94 and 141.

[3] Capt. H. W. Feilden and C. E. de Rance, Geology of the Coasts of the Arctic Lands visited by the late British Expedition under Capt. Sir G. Nares; Palaeontology by R. Etheridge; Quart. Journ. Geol. Soc., 1878, XXXIV, pp. 556–639, map and pl.

schists and quartzite, known as the 'Rawson beds.' They strike north-north-east and form the west shore of Scoresby bay up to cape Creswell in lat. 82° 40′ N. On the other side of Robeson channel they form all the land north of Polaris bay and Newman bay.

Far to the north, beyond the Rawson beds, some Devonian appears in Dana bay; on the north side of Grinnell Land, on Feilden and Parry peninsula up to Clements Markham's inlet, Carboniferous limestone is met with, precisely in the line of strike of the Carboniferous limestone of the Parry islands. Beneath the Carboniferous limestone and beyond it, up to the farthest point hitherto reached, stretch the rocks of the Rawson beds.—

The results of the preceding observations may be summed up in the following sketch.

The Canadian shield, that abraded Archaean surface which bears the shallow waters of Hudson bay, is surrounded by a ring of flat-lying Palaeozoic beds; in a few places this ring has been entirely destroyed by denudation, as in the south-east towards the lower course of the Saint Lawrence, but elsewhere it is continuous and often of great breadth. On the west the Devonian contributes to its formation, though the Silurian has not yet been observed at its base. The margin of the shield on the south and west is accompanied by a long series of great lakes. Lake Huron with its northern bays, lakes Superior, Winnipeg, Athabasca, the Great Slave lake, lake La Martre and the Great Bear lake are situated in such a manner that a larger or smaller part of each lies within the Archaean shield, the remaining part within the Palaeozoic border. The boundary then reaches Coronation gulf, probably follows Simpson straits, and runs through Melville peninsula, but has not been determined farther to the south. The Palaeozoic border is known in East Melville, on the Nettilling, and at the upper end of Frobisher bay. It is not known to be continued into Hudson strait. We find it again at Anticosti and in patches on the very severely denuded region of the Saguenay.

In the Arctic archipelago the border is formed of zones of Palaeozoic rocks, following one another in regular order and overlaid towards the north by patches of Mesozoic deposits. Towards the west, where it consists chiefly or exclusively of Devonian, the border sinks beneath the Cretaceous beds of the prairies. Towards the south it passes into the folding of the Cincinnati uplift and the folds of the Appalachians. To the south-east it is bounded by the St. Lawrence, and the folded mountains of New Brunswick and Newfoundland. To the east and north-east an independent gneiss range forms a boundary along the coast and runs from the strait of Belle Isle, on the coast of Labrador, to Hudson strait and Resolution island. Another independent lofty gneiss range, perhaps a continuation of that just mentioned, runs along the coast of Cumberland, is interrupted at

Home bay, and extends thence to cape Walter Bathurst. From there lofty gneiss or granite mountains stretch through the east part of North Devon and along the coast of Ellesmere Land to cape Sabine in Smith sound.

The numerous inlets, bays, and sounds of the Arctic archipelago lie on the flat-bedded Palaeozoic border, and the north coast of the mainland probably coincides for a long distance with the north edge of the shield.

2. *The Baltic shield.* The fundamental features of the part of North America just discussed are repeated in a remarkable manner in a part of northern Eurasia. Lapland and Finland are formed, like the Canadian shield, of Archaean rocks, which were already folded before the Cambrian period: like it, they are surrounded by a curvilinear border of flatly bedded Palaeozoic sediments, owing their exposure chiefly to later erosion by ice, and finally, like it, they are covered by a vast labyrinth of small sheets of water, which are united by a maze of streams. In both cases a number of great bays and inland seas lie on the boundary region between the Archaean and Palaeozoic rocks; the limit of the Palaeozoic girdle runs from the coast of Sweden near Oeland across the Baltic north of Gothland and north of Dagö, through the gulf of Finland, quite close to its southern shore, then through lake Ladoga, also close to its southern shore, then, with a somewhat more oblique direction to the north, through the south part of lake Onega; it reaches the sea not far from the town of Onega, probably crosses the peninsula which runs out to the north, and the gulf of Archangel, and then extends beneath the sea up to cape Voronov.

Thus the Baltic sea, like Hudson bay, represents a partial submergence of the abraded Archaean platform, though in this case the submergence is less extensive; the gulf of Finland, lakes Ladoga and Onega, and the bays of the White sea occupy a position similar to that of lakes Superior, Winnipeg, and the other oft-cited lakes of the American festoon, together with Coronation gulf and its continuations. To all these we may apply the observation, made long ago by Richardson with regard to the American lakes, that in each case without exception one part of the shore is Archaean, another part Palaeozoic, and that the lakes lying to the south of the boundary, on the Palaeozoic region itself, such as lake Peipus, lake Ilmen and others, correspond to Winnipegosis and its companions.

The Palaeozoic girdle is distinguished in its western part and even south of the gulf of Finland by the fact that the several members of the Cambrian and Silurian systems rest upon one another in regular succession, so that as the distance increases the deposits become continually more recent; but further to the north-east the red Devonian sandstone, coming from the south and east, encroaches more and more on the parallel Silurian zones, covering them out of sight one after the other, so that on the south shore of lake Ladoga none but their inner, that is older, members remain visible between the Devonian sandstone and the Archaean rocks, till finally

this sandstone comes directly in contact with the Archaean region, and on the coast of the North sea neither Cambrian nor Silurian beds are to be seen, but only Archaean rocks and the red sandstone.

This transgression of the Devonian sandstone has long been known: Murchison[1] has given a clear account of it; and since I shall have to refer to it later, the following details may be introduced here.

On the long island of *Oeland* the strike, according to Dames, follows approximately the direction of the island itself, which is elongated to the north-north-east, so that the Cambrian beds lie on its west side, and to the east of these the lower Silurian stages succeed each other in regular order[2]. *Gothland* belongs wholly to the upper Silurian; the various subdivisions of this system follow one another in ascending order towards the south-east, and, as shown on the map drawn up by F. Schmidt, their boundaries run obliquely across the island to the north-east[3].

The detailed descriptions of Grewingk and F. Schmidt show that the strike, directed in Oeland to the north-north-east and in Gothland to the north-east, is bent round beneath the sea so completely that in Dagö, Oesel, and Esthonia it runs from west to east parallel to the south shore of the gulf of Finland. The Cambrian deposits follow this coast, to the south they are succeeded by beds of lower Silurian, as in Oeland; Dagö and Oesel are formed of upper Silurian, as is Gothland, and the highest Silurian beds are exposed in the south part of Oesel. The red Devonian sandstone forms the shores of the gulf of Riga, and at the north-east corner of this gulf, near the bay of Pernan, it overlies the upper Silurian; the highest member of the upper Silurian, however, which is visible in the south of Oesel, seems to have already disappeared, and the red sandstone now advances further and further to the north, concealing the Silurian, so that between Saint Petersburg and Gatschina only the Cambrian and a narrow band of lower Silurian beds are to be seen; at the entrance of the Sjas into lake Ladoga a Cambrian zone alone is visible beneath the red sandstone, and soon nothing but Archaean rocks and red sandstone form the surface of the ground[4].

[1] R. I. Murchison, E. de Verneuil, and A. von Kayserling, The Geology of Russia in Europe and the Ural Mountains, 4to, 1845, I, pp. 41–49.

[2] W. Dames, Geologische Reisenotizen aus Schweden; Zeitsch. deutsch. geol. Gesellsch., 1881, XXXIII, pp. 415–433.

[3] F. Schmidt, Beiträge zur Geologie der Insel Gotland; Arch. Naturk. Liv-, Esth- und Kurlands, Dorpat, 1859, 1. Ser., Bd. II, pp. 403–464, map.

[4] C. Grewingk, Erläuterung zur zweiten Ausgabe der geognostischen Karte Liv-, Esth- und Kurlands, 8vo, Dorpat, 1879 (with map in Fol.); also in Arch. Naturk. Dorpat, 1. Ser., Bd. VIII; F. Schmidt, Revision des ostbaltischen silurischen Trilobiten nebst geognostischer Uebersicht des ostbaltischen Silurgebietes, Mém. Acad. Imp. Sci. Saint-Pétersb., 1881, 7e sér., XXX, pp. 55 et seq.; and by the same, On the Silurian (and Cambrian) Strata of the Baltic Provinces of Russia, Quart. Journ. Geol. Soc., 1882, XXXVIII, pp. 514–535, map, pl. xxiii.

In this region there are certainly some slight undulations in the Silurian, but the most marked of these appear to be nothing more than those accessory disturbances of dragging out or shattering, which accompany faults: generally speaking, the bedding of the Palaeozoic sediments is everywhere very flat. In striking contrast to this, the Archaean rocks are folded, and strike, as Inostranzeff has shown, along the great inland seas to the south-east, i. e. across the course of the Palaeozoic girdle; their strike determines the trend of the peninsulas in the north part of lake Onega [1].

On the south and south-east shore of this lake the predominant rock is the red sandstone, which as we have already seen occupies the eastern part of the gulf of Onega. On the little island of Ki-Ostrof, a few miles north of the town of Onega, Murchison observed granitic gneiss with vertical foliation [2].

Let us now turn our attention to the south of the Scandinavian peninsula.

A glance at the map might naturally lead us to suppose that Scania stands in an independent position. If the slightly curved coast of Bohus and Halland were directly joined to that of Blekinge, the south coast of Scandinavia would present a much more regular outline, and Scania seems to be added on as an appendage. Closer examination confirms this view. Scania is formed of fragments of a great plateau, broken up by fractures. It presents us with Mesozoic sediments which are elsewhere unknown in Scandinavia, although they once probably possessed a much wider extension towards the north. Apart from pre-Silurian and Silurian rocks we meet with red clay, usually assigned to the Keuper, then coal-bearing sediments belonging to the Rhaetic and Lias, the latter with marine beds, and finally the middle and upper Cretaceous. In one locality the coal-bearing series abuts against the gneiss, in another against the Silurian; the Cretaceous rests sometimes on the Lias, sometimes abuts against the Silurian, at others overlies the gneiss, and as E. Erdmann has shown the whole region is traversed by great longitudinal fractures which run from north-west to south-east; along these the whole country has been let down irregularly, with the formation of troughs and horsts. The investigations of Nathorst have shown further that this subsidence has taken place at different times, and that it is possible to classify the fractures according to their age [3].

[1] A. A. Inostranzeff, Carte géologique de la partie septentrionale du Gouvernement Olonetz; Matér. Géol. Russ., 1877, VII, pl. ii et passim.

[2] Murchison, The Geology of Russia in Europe and the Ural Mountains, pp. 21, 22.

[3] E. Erdmann, Description de la formation carbonifère de la Scanie, 4to, 1873 (in the publications of the Royal Swedish Geological Institution); Herr Erdmann has kindly furnished me with more recent observations on the fault lines; G. Nathorst, Till frågan

We now recognize Hallands Ås with Hallands Vaderö, north of the Skelder Vik, and the Kullen, south of this bay, as two horsts, running out to the north-west; Romele Klint in the interior of the country is a similar horst, and the projection of the land to the south-east between Ystad and Cimbrishamn is determined in like manner by the fractures, which run to the south-east. We can distinguish among these fractures those which were produced after the Silurian and before the Keuper from others which

FIG. 5. *Scania*, after G. Nathorst.

A Archaean; *s* Cambrian and Silurian; *k* Keuper; *rh* Rhaetic and Lias; *cr* Cretaceous; *δ* Diabase; Basalt shown in black. Strong lines, definitely ascertained faults; broken lines, conjectural faults.

were formed after the Keuper and before the Cretaceous, and these from yet others which were formed after the Cretaceous; and thus the deposition of the Cretaceous on the gneiss, i. e. on an old exposed horst, finds an explanation. Nathorst has shown that the horst of the Kullen, for example, as well as its probable continuation the Söder Åsen, is bounded

om de Skånska dislocationernas ålder, Geol. Fören. Stockh. Förh., 1887, IX, pp. 74–130, maps. One of the transverse fractures is clearly figured by Hauchecorne in Zeitschr. f. Berg-, Hütt. u. Salinenw., 1875, XXIII, plate *b* in text.

on the south by a fracture which is older than the Trias, and on the north by another which is younger than the Cretaceous, and in this country, which has not been subjected to any folding since the Cambrian period, we have a new and an instructive example of the breaking down of a table-land accomplished piece by piece and at different times. A few short transverse fractures, running to the north-north-east, also occur. The older diabase dykes follow the master fractures to the south-east, and the younger basaltic dykes appear to correspond to the north-north-east strike of the transverse fissures.

Bornholm is the continuation of this fractured table-land or rather of the horst, formed of gneiss and Palaeozoic sediments, which projects at Melby Åsen and near Cimbrishamn. In the south-west part of Bornholm the subsided coal-bearing series of Scania is visible, together with down-thrown patches of Cretaceous[1].

Now that we have separated off Scania and Bornholm let us cast a glance over the great peninsula of Scandinavia.

A lofty range of mountains rises in the west facing the Atlantic Ocean; to the east and south next the Baltic and the Skager Rack extends a broad tract, lying at a low level in the whole of the south part of the peninsula, and consisting chiefly of Archaean rocks. The boundary between the mountains in the west and the Archaean land in the east is marked by a great scarp, which may be followed from Stavanger in lat. 59° N. into the northern part of the district of Tromsö in lat. 70° N.: it describes an irregular and frequently interrupted line, but on the whole follows the main direction of the peninsula. Although the mountainous region consists in great part of folded ranges which mostly run out to the Atlantic coast, cutting it obliquely, yet much of the eastern slope presents us with beds which lie quite flat, and facing it on the east there rise from the Archaean region isolated mountain masses, formed of the same horizontal beds, which must evidently be regarded as outliers of the great escarpment. Thus the face of the escarpment certainly does not correspond as a whole with a continuous fracture; over the greater part of its course it is without doubt a denudation boundary, and as Pettersen rightly pointed out, when describing its northern part many years ago, the mountains in that region must once have extended beyond the escarpment much further to the east than they do at present.

The Archaean region is bounded on the east by that flat-bedded Silurian belt which borders the peninsula west of Oeland, and thence runs as we have already seen beneath the Baltic to the gulf of Finland.

[1] K. v. Seebach, Beiträge zur Geologie von Bornholm, Zeitsch. deutsch. geol. Ges., 1865, XVII, pp. 338-347, pl. viii; M. Jespersen, Bidrag til Bornholm's Geotektonik, Nat. Tids. Kjöbenh., 1867, 3. R., V, pp. 33-52, pl. vii; Nathorst, Till frågan om de Skånska dislocationernas ålder, Geol. Fören. Stockh. Förh., 1887, IX, pp. 116 et seq.

It includes the south of Norway and most of Sweden. It rises towards the north, where it is covered by dense forest; in the south it bears the great lakes; everywhere it shows traces of the grinding action of the ice. It was formerly covered by a continuous sheet of Silurian beds, and the isolated fragments of this sheet which have escaped destruction doubtless owe their preservation to subsidence. The most important of the downthrown patches is the remarkable band of Silurian deposits, more than 200 kilometers long, which runs from the east slope of the mountains to the south-south-west across lake Mjösen and Christiania, and then down the west side of the fjord; its middle part is often spoken of as the Silurian region of Christiania.

This band has indeed experienced strange vicissitudes. Considerable parts of it first underwent folding and subsequently abrasion; then it was broken up into segments and subsided; later or perhaps simultaneously, copious injections of a red granite, the Drammen granite, welled up into it; then it was traversed by more recent eruptive dykes, and finally cut up by a number of smaller trough faults, which form the existing transverse valleys[1].

In the north, on lake Mjösen, the folding is very intense, and over-folding also occurs. At Christiania the folding is equally intense; south and south-west of Christiania the coasts of the fjord afford many well-known examples of structural features, such as intrusions of more recent granite in the form of laccolites, with an altered roof of Silurian limestone; fractures bringing the Silurian beds against the ancient gneiss; and finally horizontal displacements of orographic blocks. On this coast also, to the south-west, are found the admirable examples of small trough faults which have been described by Kjerulf. Brögger has given an extremely instructive account, describing in detail the movements of the mass and the history of its injection[2].

Still further to the south, between Skien and Langesund, folding has

[1] T. Kjerulf, Dislokationerne i Kristiania dalen; Nyt Mag. Naturvid. Christiania, 1883, XXVIII, pp. 79–88 and 171–197, and in many other publications.

[2] W. C. Brögger, Die silurischen Etagen 2 und 3 im Kristianiagebiet und auf Egger, Universitäts-Programm für das 2. Semester 1882, 8vo, Kristiania, 1882; and in particular by the same, Ueber die Bildungsgeschichte des Kristiania fjords, Nyt Mag. Naturvid., 1886, XXX, pp. 96-244, map; further, Om Kristiania fjordens Dannelse, Naturen, 1886, no. 7, 8; also A. Penck, Ueber einige Kontaktgesteine des Kristiania-Silurbeckens, Nyt Mag. Naturvid., 1881, XXV, pp. 62–82; E. Reyer, Vier Ausflüge in die Eruptivmassen bei Christiania, Jahrb. k.-k. geol. Reichsanst., 1880, XXX, pp. 27–42, &c. I have myself had an opportunity of visiting with Herr L. Burgerstein some of the most characteristic points of contact of the Drammen granite with the Silurian deposits, of collecting at the zone of contact fragments of Halysites converted into Vesuvian, and of convincing myself as to the correctness of Kjerulf's description of the Drammen granite. Brögger's investigations are among the most detailed which we possess on the formation of a great trough.

disappeared. The narrow strip of Silurian rocks rests towards the west on gneiss and towards the east it sinks with a rapidly increasing dip, that is as though by flexure, beneath a very extensive mass of syenite. This narrow strip is also traversed, as shown by Brögger, by longitudinal and transverse faults and by many intrusive dykes; the various segments have been let down to different depths. Brögger has at the same time shown that the subsidence of these segments and the ascent of the eruptive rocks are probably connected phenomena[1]. Since, however, the island of Nord Koster also belongs to the Silurian, it is possible that the whole coast up to the faults of Scania will prove to be a continuation of the eastern fracture.

To the east of the great downthrown zone, fragments of ancient sedimentary masses are also faulted in; these occur on the south-east side of lake Wenern, between this lake and lake Wettern, on the east shore of lake Wettern, north of this lake, and in other places; Nathorst is even of opinion that the line of demarcation between the gneiss and the granite, so sharply defined in south Sweden, represents a great pre-Silurian fault. The supposed fault would run from the neighbourhood of Sölvesborg, on the south coast, towards the north, crossing obliquely the southernmost part of lake Wettern, and touching the east side of lake Wenern it would then proceed, with a slight deviation towards the north-north-west, up to the high mountain ranges. It would extend from lat. 56° to lat. 61° N., and the downthrown part would be the gneiss forming the west limb. The intrusions of hyperite, which make their appearance in the gneiss close to the supposed fault-line, might then be a direct consequence of the subsidence itself[2].

The view that great subsidences have affected this Archaean region in ancient times appears to be rapidly gaining ground among Scandinavian geologists, and Svedmark has drawn up a whole system of conjectural lines of fracture in the region extending north of Stockholm as far as the sea of Åland, which is distinguished by its extraordinary depth[3].—

The mountain region, which is to no small extent a true table-land, presents a fundamentally different character.

From Kragerö in the east to Stavanger in the west, the whole south coast of Norway is formed of gneiss and granite, and the same rocks passing through Christiansand form all the country far into the interior. This is the western part of the Archaean region. Above it, extending

[1] W. C. Brögger, Spaltenverwerfungen in der Gegend Langesund-Skien; Nyt Mag. Naturvid., 1884, XXVIII, pp. 253–419, map.

[2] G. Nathorst, Ett försök att förklara orsaken till den skarpa gränsen mellan södra Sveriges vestra och östra urterritorium; Geol. Fören. Stockh. Förh., 1886, VIII, pp. 95–102.

[3] E. Svedmark, Orografiska studier inom Roslagen; Geol. Fören. Stockh. Förh., 1887, IX, pp. 188–210, map.

from Stavanger to the north-east, a steep scarp rises which runs in and out with an irregular lobate outline; this is the edge of the extensive Langfjeld and at the same time the beginning of the great eastern slope. The most striking feature presented by this scarp is the contrast it offers to the regions lying more to the east in the thickness attained by the Cambrian system, owing to the intercalation of great masses of quartzite and schists. Tellef Dahll has examined a part of it to the north-east of Stavanger; he found that the escarpment was formed of approximately horizontal beds of quartzite and lustrous schists, and in the Huulberg, where the boundaries of the three southern dioceses of Norway unite, he discovered in the lower part of this series a bed with *Dictyograptus flabelliformis* (= *Dictyonema sociale*); the whole series is therefore assigned to the 'primordial' stage. On the Hallingskarve, near the upper end of the Hardanger fjord, a recent granite is found, according to the same observer, overlying this series. In other places superimposed masses of mica schist and hornblende schist are described as piled high above it[1].

The flat-bedded series of schists and quartzites is continued to the north-east over a part of the Vidden, through Hallingdal and into the Gudbrandsdal; it forms also some isolated masses which face the east border of the mountains. The quartzite of the great ranges must be regarded as a higher member of the series, but in this region also mica schists, augen-gneiss and hornblende schists are said to occur high on the summits. The arrangement of the beds, however, is not sufficiently known[2].

To the north of this region rise the rugged mountains of the Jötun fjeld, formed of gabbro. The sketch-map published by Reusch gives the impression that this series of great masses of gabbro marks the boundary between the flat-bedded eastern part of the range and the western folded part[3].

The flat-bedded girdle soon changes its character, and we reach a region which it is particularly difficult to describe in detail. I follow the data given in a series of masterly descriptions by Kjerulf[4].

On the side of the Gudbrandsdal the flat-bedded series presents itself as an alternation of schists and blue quartzites; hitherto they have rested on the Archaean rocks; now a mighty series of feldspar-bearing sandstone, the 'sparagmite' of Norwegian geologists, is inserted beneath them; the

[1] Tellef Dahll, Ueber die Geologie Tellemarkens, translated into German by W. Christophersen, 4to, Christiania, 1860, pp. 16–19.

[2] Kjerulf, Die Geologie des südlichen und mittleren Norwegen, p. 184.

[3] Hans H. Reusch, Die fossilienführenden krystallinischen Schiefer von Bergen in Norwegen, German translation by R. Baldauf, 8vo, Leipzig, 1883, p. 5.

[4] Of these I will only mention Geologisk Oversigtskart over det sydlige Norge, fol. 1878, and T. Kjerulf, Die Geologie des südlichen und mittleren Norwegen, German translation by Gurlt, 8vo, Bonn, 1880.

upper part of this series yields Paradoxides and may therefore be definitely assigned to the Cambrian system. In the lower part of the sparagmite lies the unfossiliferous zone of the Birid limestone. But while the sparagmite with the Birid limestone lies beneath the schists and blue quartzite, the richly fossiliferous series of the lower Silurian lies above the stage of the blue quartzite and, as it appears, unconformably, so that the Orthoceras limestone, for example, rests on different stages of the Cambrian system. At lake Mjösen the lower Silurian is present in considerable thickness, and it is from the neighbourhood of this lake that the long strip of faulted-down Silurian branches off to the south-south-west, and, as we have already seen, reaches the sea by way of Christiania, thus dividing the Archaean region into two parts. The thick accumulations of the Cambrian, with which we have just become acquainted as the blue quartzite and the sparagmite stage, do not accompany this band.

On the Herjehogna, a peak 3,800 feet in height, situated in Dalarne at about lat. 61° 30′ N., the rampart of quartzite crosses the Swedish frontier. It marks the eastern edge of the mountains, but not, in this region, the east boundary of the sedimentary beds which are superposed on the Archaean foundation, for in front of it and emerging from beneath its foot the continuation of the Norwegian sparagmite, here called the Dala-sandstone, makes its appearance and extends at no great height over a great part of southern Dalarne.

For a knowledge of these regions and of those extending to the north through Herjeådalen and Jemtland to lat. 64° N., the works by Törnebohm published in 1873 are the chief source of information, and it is the results obtained by this indefatigable observer which will now be my guide [1].

The quartzite which forms the great rampart, here called the Wemdal quartzite, is the continuation of the high-mountain quartzite of Norway; the rampart bounds the mountainous region. At its foot, a little north of lat. 62° N., the sparagmite disappears, yet the rampart does not rest directly on the Archaean rocks; for close to its foot a series of Silurian beds is intercalated, in particular the Orthoceras limestone; this accompanies the quartzite rampart into the neighbourhood of Årsarnes Kapell, in about lat. 62° 45′ N., forming a narrow belt, and according to Törne-

[1] A. E. Törnebohm, Ueber die Geognosie der schwedischen Hochgebirge; Bihang svenska Vet. Akad. Handl., I, no. 12, 1873, map; Sver. geol. Undersökn., ser. C, no. 9. Part of this previously appeared in En geognostisk Profil öfver den Skandinaviska Fjällryggen mellan Östersund och Levanger; by the same, Öfvers. K. Vet. Akad. Förh., 1872, and Sver. geol. Undersökn., ser. C, no. 6, 1872. Törnebohm has distinguished in the high mountain beds two groups, the Seve and the Köli; but subsequent observers do not seem to have considered these new designations necessary. A good general geological map of the region around the Stor Sjön is contained in A. G. Högbom, Glaciala och Petrografiska Jakttagelser i Jemtlands Län; Sver. geol. Undersökn., ser. C, no. 70, 4to, 1885.

bohm underlying the quartzite. From this point the rampart recedes very far towards the north-west, only advancing again in the north, and it thus forms an irregular arc within which the Silurian beds are distributed with horizontal bedding. On these tabular masses of Silurian lies the great lake of Stor Sjön. Towards the east these masses rest on the Archaean rocks, which here, however, attain a greater elevation than in the south, and even rise higher than the Silurian table-lands.

We now scale the quartzite rampart and reach the mountainous region, on which several summits attain a height of 5,000 to 6,000 feet; a considerable part lies above the limit of forest growth, i.e. over 2,800 feet. Here a lower group may be distinguished, consisting of quartzite and mighty masses of crystalline schists, namely mica schists, hornblende schists, and even gneiss; and an upper group which comprises semi-crystalline clay slates and likewise hornblende schists. Strange though it may seem to encounter gneiss and hornblende schists high above the Silurian in normal superposition, yet we must remember that a precisely similar phenomenon has been observed by Norwegian investigators in the south part of the great mountain border. In short, the succession of rocks as given by Törnebohm is as follows: older granite (Archaean); on this, Dala-sandstone (sparagmite, only in the south); Silurian in the north-east up to the horizon of the Pentamerus limestone; then Wemdal quartzite, which forms the great rampart above the Silurian, and above this another mighty series of highly crystalline schists.

The conclusions arrived at by Törnebohm have been disputed. Svenonius, as the result of a series of detailed surveys, considers that the narrow belt of Silurian deposits at the foot of the quartzite rampart, and with it the expanse of Silurian about Stor Sjön, do not really underlie the quartzite; the quartzite is certainly traversed by several folds, while the Silurian shows absolutely no signs of folding; thus the quartzite rampart represents a Silurian shore, and the Silurian was deposited against it, as well as in the pre-Silurian valleys [1].

This view, however, which accords so well with the older conceptions of the great antiquity of the crystalline schists, was destined soon to undergo great modification, chiefly owing to the continued labours of the same conscientious investigator. The most important of the fresh observations was the discovery of Silurian fossils at many localities within the great ranges themselves. The untiring zeal of Scandinavian geologists

[1] F. Svenonius, Till Frågan om Förhållandet mellan 'Wemsdal's-Quartsiten' och siluriska Formationen inom södra Delen af Jämtlands Län; Sver. geol. Undersökn., ser. C, no. 49, 8vo; also Öfvers. K. Vet. Akad. Förh., 1881, no. 10. Högbom has since shown that parts of the east border of the Silurian region are faulted down into the Archaean foundation. By the same, Om förkastnings-breccior vid den Jämtlandska Silurformationens östra gräns; Geol. Fören. Stockh. Förh., 1886, VIII, p. 352.

will certainly succeed in dissipating at last the doubts which at present exist as to the relation between the Silurian table-lands of the Stor Sjön and the high mountain ranges. Let us now turn our attention to the north while continuing to follow the eastern boundary of the mountains.

A little way to the north, very nearly in lat. 64° 30′ N., where the Sjougdelv, coming from the west, flows into the Tasjon, Svenonius met with fossiliferous Cambrian deposits. These are folded with the quartzite and lie in a synclinal of this rock[1]. In the northern part of Jemtland and in Westerbotten, a new element now makes its appearance in the mountain border, namely, a very long series of large and small masses of olivine rock and serpentine, which are intercalated like sills with the schists of the high mountains.

East of Grong, in the midst of the Norwegian mountains, in lat. 64° N., Hauan met with a great mass of anorthite olivine rock[2], the beginning, apparently, of an extremely long band, which follows the general strike of the mountains from here towards the north-north-east, crosses the Swedish frontier, and becomes visible on the east slope. Many isolated exposures had been known from comparatively early times; Svenonius has shown their continuity. The largest masses are the Rödfjället on the Stor Blåsjön near the headwaters of the Sjougdelv, mentioned above, and the mountains of Graipies and Orna, which lie in close proximity to one another north of Fatmomak (lat. 65° N.). The series is continued much further still: mountains of olivine occur even beyond lat. 67° N. to the south-west, west, and north-west of Kvikkjokk.

It was in this region also that Svenonius was quite recently led to assign a 'post-Azoic' age to these mighty, high-mountain formations, owing to the discovery of fossils, particularly of a bed containing Hyolithes in the Paije Sartajaur and of Encrinite joints in the high mountains. The same observer has had the kindness to inform me that he has now found the Hyolithes beds in five or six places in Norbottens Lappmark, but not yet in Jemtland, and, on the other hand, he has met with fragments of Crinoids in the extreme northern part of Jemtland and at some localities in Westerbottens Lappmark, in the calc-mica schist of the high mountains. The beds of Hyolithes appear to underlie the mountains and form a belt along their eastern boundary.

[1] Svenonius, Om 'Seve gruppen' i nordligaste Jämtland och Ångermanland, samt dess Förhållende till fossilförande Lager; Sver. geol. Undersökn., ser. C, no. 45, 8vo, and Geol. Fören. Stockh. Förh., 1881, V, pp. 434–497, pl. xx, xxi.

[2] Kjerulf, Geologie des südlichen Norwegen, p. 272.

[3] Svenonius, Om Olivinstens och Serpentin förekomster i Norrland, Sver. geol. Undersökn., ser. C, no. 56, and Geol. Fören. Stockh. Förh., 1883, VI; by the same, Studier vid Svenska Jöklar, Sver. geol. Undersökn., ser. C, no. 61, and Geol. Fören. Stockh. Förh., 1884, VII, pp. 5–38, and Nya olivinstens förekomster i Norrland, tom. cit., ser. C, no. 61, and Geol. Fören. Stockh. Förh., 1885, VII, pp. 201–210.

We now enter a region which has been made known in its general outlines by Hummel's survey, and by a section drawn by K. Pettersen across the peninsula, from north-west to south-east, i.e. from Saltdalen to Piteå[1].

The peninsula consists here, according to Pettersen, of the following parts. The gulf of Bothnia is bordered on the coast by a narrow belt of lowland, formed of gneiss in steeply upturned beds. The country then suddenly rises towards the interior to a height of about 1,100 feet, and from here there extends a monotonous granitic highland, for the greater part covered by forest and about 200 kilometers broad. It rises very slowly on the west towards the zone of the great lakes, so that the water-level of the Saedva for example, west of the Hornafvan, lies 1,420 feet above the sea. Towards the lakes some degree of variety replaces the monotony of the east; isolated ranges rise some hundreds of feet above the surrounding country. Finally, at the west end of the Hornafvan and between this great lake and the Laiselv, which follows on the south, we reach the great rampart, which still marks the east edge of the mountain highland. Its highest ridge lies at a height of about 2,500 feet. It appears from Hummel's observations that the northern continuation of the rampart is crossed by several of the great lakes; this is the case to the east of Kvikkjokk, and the Torneå Träsk lies in such a manner that almost its whole western part is let down into the mountain highland, while the larger, eastern part lies outside it.

Above the rampart, a little way to the south, there rises the isolated peak of Peljakaisse (1,064 meters), which lies 275 kilometers from the gulf of Bothnia, and 187 kilometers from the Atlantic Ocean; and now the snowy peaks crowd higher and higher towards Sulitjelma (1,875 meters) and the far higher summits in the north, namely Sarjektjåkko (2,128 meters) in Luleå, and Kebnekaisse (2,156 meters) in Torneå Lappmark[2].

The rampart itself from north Jemtland up through Lappmark consists, so far as yet known, of a mighty series of strata lying horizontal. Pettersen distinguishes a group of beds at the foot of the rampart, which

[1] David Hummel in Underdånig Berättelse om en på nådig Befallning är 1875 företagen Undersökning af Malmfyndigheter inom Gellivare och Jukkasjärvi Socknar af Norrbottens Län, Sver. geol. Undersökn., 4to, 1877; see also pl. i in this memoir, Geologisk Öfversigtskarta öfver den kända Delen af Norrbottens Län, and pl. ii, Geologisk Karta öfver en del af Torne och Lule Lappmarker; Karl Pettersen, Det nordlige Sveriges och Norges Geologi; med et geologisk Profil over den Skandinaviske Halvö fra Saltdalen til Piteå, in Lie, Müller and Sars, Archiv. Math. Naturvid. Christiania, 1878, III.

[2] Svenonius, Några ord om Svenska Lappland, in the publication called 'Heidrun,' February and March, 1885, pp. 26–33. The altitudes, as Herr Svenonius informs me, are taken from 'Norrbottens läns Ekonomiska Kartwerk' and rest on trustworthy measurements.

he calls the Dividal group, after a valley in Tromsö stift, south of the Bals fjord; it consists of fine-grained schists, red, green or grey in colour, of quartzite and quartz schists, and corresponds to that zone in which Svenonius found Hyolithes; we assign it to the Cambrian system. Above this group lies the group of the Tromsö mica schists, composed of mica schists and quartzite.

In order to discuss the further continuation of the rampart beyond the Torneå Träsk, so far as it is known, we must first consider the main features in the structure of northern Norway. Pettersen's extensive investigations and the geological map by Tellef Dahll are the most important sources of information [1].

First of all, it must be borne in mind that the great chain of islands which borders the mainland on the west, the Lofoten and the Westeraalen, is formed of gneiss and granite, evidently of very great age; and thus these islands probably exhibit the oldest rocks which exist in the mountain ranges of the north [2]. We shall soon see that the Hebrides similarly present us with the most ancient rocks of Scotland. In the north-east part of the northernmost of these islands, at Ramsaa, in the island of Andö, there lies a small patch of more recent sediments. At one time coal mines were worked here, now said to be filled up. Some slabs of sandstone filled with valves of Aucella, to be seen in the museum at Tromsö, show that these sediments are those Mesozoic deposits of the north which once extended from Spitzbergen to Andö [3]. This isolated patch lies close to the sea-coast, and although the data as to the lie of the beds are very incomplete, yet the similar patches in Scotland show that we probably have here a faulted-down fragment, preserved as the last remains of a deposit which formerly extended over a wide area.

Another element of particular importance in the structure of the country is the lofty and extremely rugged mountain range, which strikes to the north-north-east and separates the Lyngen fjord from the Ulfs fjord

[1] Tellef Dahll, Geologisk Kart over det Nordlige Norge, mit Bistand af Corneliussen, Hjortdahl, Lassen og C. Pettersen, fol., Christiania, 1886–1879: Pettersen's later treatises are contained partly in the Tromsö Museum's Aarshefter, partly in Arch. Math. Naturvid. of Lie, Müller, and Sars. Pettersen distinguishes three groups of stratified formations: Dividal group, Tromsö mica schist, and Bals fjord group; the latter has recently been regarded as older than the Tromsö mica schist; since however this question is not of primary importance for the subjects treated here, I have not quoted, besides the Dividal group, any other members in the table-land, or, as it is usually called in Norway, the high mountain series; cf. Pettersen, Balsfjordgruppens plads i den geologiske Følgeräkke, Tromsö Museum's Aarshefter, VI, 1883, pp. 87–97. Several of the most important rocks of these regions are described by Philippson in Verh. naturh. Ver. preuss. Rheinl., 1883, XL, Sitzungsber., pp. 190–210.

[2] Pettersen, Lofoten og Vesteraalen: Arch. Math. Naturvid., 1881, V, map.

[3] Among the plant remains of Andö are two species of Pinus which O. Heer has compared with those of Spitzbergen.

on the west. Its black, terribly steep peaks rise to a height of about 1,800 meters above the sea; glaciers descend between them; the contrast with the gentler mountains of the surrounding country is extremely striking. The outlines recall, by their savage aspect, the tonalite crags of the Presanella in Tyrol. This range, which may be clearly seen on the map by Tellef Dahll, consists of gabbro and serpentine, and resembles to some extent the great 'cicatrice' of gabbro which forms the Jötun mountains in the south.

Not far from the place where the upper extremities of the Bals fjord and the Lygen fjord approach each other in the south, rises the steep pyramid of the Pig-tind, which is a part of the Lyngen range; a long, abrupt, but low ridge of gabbro, which strikes south of the Bals fjord obliquely to the west-south-west through the great valley of the Maalselv, may perhaps be considered as a continuation of this range, bent into the strike of the mountains; but it is hard to say. Even much further to the west-south-west, e.g. at the foot of the Istind in Bardo, numerous injections of eclogite and gabbro are visible, as though a zone of fracture and intrusion ran from Arnö in the north through Lyngen, and then parallel to the main strike across the valley of Bardo.

The rocks which appear on the west of this zone towards the islands and in the islands themselves, up to the ancient gneiss, exhibit many disturbances, but in the interior of the Bals fjord, as well as towards Malanga, the well-stratified mountain masses assume more and more the form of broad blocks, sometimes gently inclined, sometimes lying nearly horizontal. Violent local folding is present, but the mountain structure, as a whole, is not that of a folded range.

The country lying to the east of the zone of intrusions, or the zone of the Lyngen gabbro, forms a continuous zone of stratified rocks extending to the east border of the mountains, i.e. to the great rampart. This is the zone of the high mountains, properly speaking. It is composed of clay slates, quartzite, and a later mica schist.

The desire to become acquainted with one of the valley systems which open into the northern fjords, as far as the watershed, led me to visit these mountains, and the abundant directions and explanations with which Herr Pettersen kindly furnished me, enabled me in a short time to obtain some insight into their peculiar structure. Dr. Leo Burgerstein did me the favour of accompanying me[1].

[1] I owe particular thanks to my companion, Dr. Leo Burgerstein, who, with true self-sacrifice, strove to reduce for me, as far as possible, the inconveniences of such a journey, and thus enabled me to devote my whole time to my work. Most of the localities mentioned here may be seen on Pettersen's general map of the south part of Tromsö district, in his Geologiske Undersögelser in den Tromsö Amt og tilgrændsende Dele af Nordlands Amt; K. Norsk. Vid. Selsk. Skr., 1874, VII, pp. 261-444 and pl.

Travelling southwards from the Malangen fjord to the lake of Torneå we reached the plain of the Stromsmoen (lat. 68° 48′ N.; 61·5 meters); and here, just where the Sördal, coming from the south, opens into the valley of Bardo, there rose before us a marvellous scene. Lofty mountains of horizontally stratified quartzite surround the plain, and reach a height of as much as 2,000 feet above the valley bottom: Borgsklatten in the east, Björnefjeld and Storfjeld in the west, and the wedge-shaped Rubben, which separates Sördal from the upper Bardo, in the south. Round about the plain there runs at a uniform level from one mountain mass to another a narrow band of startling whiteness, looking as though it had just received a coating of whitewash. This is a bed of limestone which, intercalated with the dark quartzites, not only renders obvious

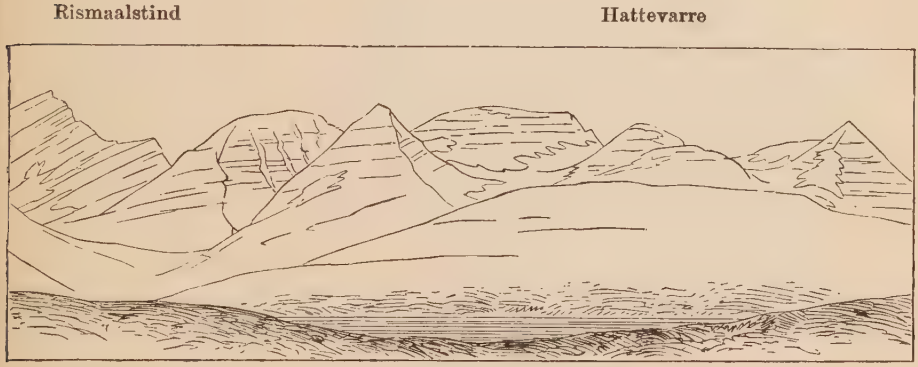
FIG. 6. *View from the Omasvarre, south of the Bals fjord,*

the horizontal bedding, but also shows that this valley has been produced solely by erosion [1].

From here we continued our journey 25 kilometers further to the south through the Sördal to the frontier, always among mountains formed of flat-lying beds. In its upper course the stream has cut for itself an inaccessible ravine, and we now ascend towards the south-east the ancient glacier bed of the Stagenuni (782 meters). Here we find ourselves standing above the quartzite, on coarsely foliated mica schists of a dark-grey or pinchbeck-brown colour. The great sheet of water which forms the north-west part of the Torneå Träsk now lies spread out before us in incomparable beauty. On our right the opposite shore is bordered by a tongue of flat woodland, corresponding with the mouth of the Nuorajoki; further away to the left, the steep walls of the moun-

[1] This white band has also been observed by Pettersen, Notiser vedrörende den nordnorske fjeldbygning; Geol. Fören. Stockh. Förh., 1886, VIII, p. 466.

tain Abesko advance close to the water's edge, and its broad but noble forms are mirrored in the lake. In the background there rise one above the other the white rounded, or dome-like summits of the mountains of Torneå Lappland. All the country visible at a little distance—the cubical summits of the west side of the Sördal, such as Spikalomi, and the equally high mountains of the east side, such as the Etnamjoski peak, which belongs to the great group of the Duoddarats—is composed throughout of horizontal beds up to a height of more than 3,000 feet above the sea-level. We are thus standing on a fragment of true table-land, and descending to the lake we find its extremity divided by a projecting reef of quartzite with the bedding equally horizonal. The great rampart however lies, as Hummel has shown, still further to the east.



Tromsö stift (lat. 69° 8′ N.) towards the east.

The structure of the mountain land lying south of the Bals fjord may be seen from the sketch (Fig. 6), made from the broad ridge of the Omasvarre (670 meters, lat. 69° 8′ N.), situated 11 kilometers south of the end of this fjord. It was drawn looking to the east, and on the left, i.e. towards the north, a few of the peaks of the Lyngen range are visible.

These peaks excepted, all the mountains are well stratified; the colouring, the alternation of schist and quartzite, and the long lines of snow resting on the ledges, all combine to bring out the lie of the beds in clearest detail. On the right, not only the broad mass of the Ruostafjeld (1,672 meters), just outside the limits of the sketch, but all the mountain land far to the south is formed of horizontal beds. The first mountain represented on the right, the southernmost member of the group of the Hattevarre, has the form of a regular pyramid, yet it nevertheless equally consists of horizontal beds. The beds of the principal mass of the Hattevarre are also nearly horizontal, but towards the Rismaalstind

inclination sets in and increases towards the north; in the Rismaalstind itself the dip is already very marked, and in the Hölltind it has become so steep that the north flank is formed by a single bedding plane; this plane plunges into the Bals fjord, and the mountains which we see further away towards the Lyngen range also form part of the side of the fjord. There is nowhere any trace of folding in this extensive range. It would rather seem as though *the whole table-land plunged in a single mighty flexure down to the gabbro of Lyngen*, and in fact Pettersen published some years ago a section taken a little more to the north, across the Lyngen fjord, in which the whole mass of stratified formations is represented as bending in an arc beneath this range of gabbro. At that time Pettersen even thought that the gabbro was intercalated with the stratified formations, and shared with them a common dip. I have not myself visited the mountains in the immediate neighbourhood of the gabbro range[1].

At the foot of the Ruostafjeld, mentioned above, a long valley opens—the Dividal—which comes from the south-south-east; its right slope may be regarded as the continuation of the section just discussed. It is after this valley that Pettersen has named the lowest member of the high mountain series. Ascending the valley we met the Dividal stage, represented by shales which resemble in every particular the Cambrian shales of Ginec in Bohemia. We found no fossils, but typical plaited slabs such as occur in the 'primordial' deposits of Sweden. We followed the Dividal for a distance of 36 kilometers, always with mountains formed of flat-lying beds on both sides, and then turned to the west into the Skakterdal, where it joins the Dividal, and ascended it to the edge of the table-land, that is, to the great rampart. Here we perceived that to the south-east the Archaean foundation, and with it the whole of the superimposed series, gradually rises towards Sweden. At the bottom of the Dividal we saw the lowest members of this series; further to the south Pettersen has even found the Archaean rocks exposed in the bed of the Dividal itself. From here (Hütte Frihedsli, 187 meters) we were obliged to ascend through the Skakterdal to a height of 724 meters in order to reach the junction with the overlying beds.

Our way led us over broad rocky floors, polished and strewn with blocks which looked as though they had only yesterday been abandoned by the glacier, until finally the table-land terminated in two great cubical mountain masses, Store Jerta on the right, Namna on the left, which seem to guard, like towers, the mouth of the pass. Through this we step out into a moraine region dotted over with innumerable pools of water, the Tjoalma Vagge (lat. 68° 40′ N.).

Looking backwards from this desolate table-land we now see that the

[1] Pettersen, Profil fra Rigsgrændsen over Lyngen til Kvalö; Forh. Vid. Selsk. Christiania, 1868, pp. 155–158, pl.

great rampart is here divided into a series of table mountains: Julos Varre, Store Jerta, Namna, Bumansberg, Kälbir Varre, and others. From the anterior slope of those nearest us, the Store Jerta, Namna, and Bumansberg, there advances with a particularly steep descent an intercalated bed of solid rock, which enables us even from a distance to perceive the original continuity of all these several bastions.

Thus the great rampart is here broken up into bastions; and it is easy to see that it was through the gaps between them, and in particular through that between Store Jerta and Namna, which leads down to the Skakterdal, that the ice-cap which once rested on the table-land thrust forth its glaciers towards the Atlantic Ocean.

Outside the bastions, on the barren table-land, below the moraines of

FIG. 7. *Tjoalma Vagge, Moraine landscape on the boundary between Norway and Sweden* (lat. 68° 40′ N.).
In the foreground the ground-down *roches moutonnées* of the red Swedish granite, in the distance the superposed table mountain.

Tjoalma Vagge, moutonnéed bosses project which belong to the Archaean foundation. This is formed of a bright-red granitic rock, of distinctly banded structure; it strikes to the north, and dips at about 30° to the east. It is the source of those red blocks which have been carried out to the west into the fjord; these will be discussed later.

The ancient rocks of the Lofoten and Westeraalen, particularly the granite, gneiss and ancient mica schists, frequently accompanied by bosses of gabbro, are continued in the same direction along the Atlantic coast. They occur in the island of Arnö, form that part of the peninsula of Meiland between the Rejsen and Kvänangen fjord which is turned towards the sea [1], as well as the whole northern part of the great peninsula of Berg, which follows next, then wholly or in great part the islands of

[1] Pettersen, Kvænangen, Tromsö Mus. Aarsh., IV, 1881, describes Bergs and Meilandshalvö, together with Spildern, Rodö, and Haukö, as once continuous rocky rampart.

Stjernö, Seljand, Sorö, Kvalö, as well as the whole north-west part of the Porsanger peninsula, together with Hjelmsö, and we meet with them on Magerö extending up to the North cape. The islands, together with the most projecting parts of the mainland, thus form the continuation of the range of the Lofoten. The greater part of this range is 1,000 feet higher than the regions which succeed it towards the interior; it is broken across by the fjords.

Within this western range of gneiss lies the table-land, and the base of this, i.e. the lowest beds of the Dividal group, now also makes its appearance on the northern edge, as for example, on the east side of Kvänangen, at Alten, on the south side of Lerbotn, in the Komak fjord, and in the Rippe fjord on the west side of the Porsanger peninsula (lat. 70° 30′ N.). These exposures mark the boundary of the table-land against the western range of gneiss. In Lerbotn the Dividal beds are steeply upturned and the gneiss is not seen; in the Komak fjord they lie horizontal, and the gneiss is also horizontal; in the Rippe fjord they are intensely folded, while the older rocks are not folded, but exhibit fairly undisturbed bedding. With complete justice Pettersen concludes that the Rippe fjord is traversed by a great dislocation, and that the table-land lying towards the interior is thrown down against the gneiss range [1].

The line of demarcation between the gneiss range and the table-land is thus a zone of dislocation, and this dislocation runs across those parts of the mainland which project into the sea and across a number of fjords. The table-land, here formed chiefly of schistose quartzite, extends from it over a wide area as far as the eastern rampart, so often mentioned above.

While the gneiss zone as a rule has a height of 3,000 feet, the table-land in its western part does not rise to more than about 2,000 feet. Its east border is little known. We left it in Tjoalma Vagge; Pettersen observed the base of the superposed beds on the upper Rejsenelv, not far from the Norwegian frontier; there the mountain mass of Reisduoddar Haldi, consisting of gabbro and serpentine, rises on the edge of the table-land to a height of 4,000 feet [2].

According to Tellef Dahll's map the edge of the superposed beds now recedes a little, advancing again towards the south in the direction of Kautokeino. Leopold von Buch, after having crossed south of Alten

[1] Pettersen, De Norske Kystströgs Geologi, IV, Porsanger-halvöen; Arch. Math. Naturvid., X, 1884, map, in particular p. 167. It is a pleasing fact that in the extreme north, in lat. 70° 30′ N, where hardly a tree or even a bush rejoices the eye, this observer has arrived by an unprejudiced contemplation of nature at the same views of the subsidence of great mountain segments which have elsewhere, under much more favourable conditions, only been adopted after much discussion.

[2] Pettersen, Ueber das Vorkommen des Serpentins und Olivinfels im N. Norwegen; N. Jahrb., 1876, pp. 613-622.

horizontal beds of quartzite and mica schist, ascended this slope from the Tjolmi-jaure towards Kautokeino and there reached the granite [1].

In the north we possess the observations of Tellef Dahll. According to these the boundary of the table-land runs from the neighbourhood of Kautokeino, along the Altenelv to the north, and on the river regular beds of graphite occur, intercalated with the stratified formations. Near the Jes Jaure, where serpentine crops out, the boundary turns to the north-east; it reaches the end of the Porsanger fjord and thence runs to the east. Raste Kaisse, south of the Lakset fjord, 3,000 feet high, and presenting beds of sandstone 2,000 feet thick, lies on this boundary, which reaches the western end of the Varanger fjord; the south side of this fjord belongs to the Archaean region, the north side to the table-land [2].

In the north of the peninsula we may thus distinguish three chief elements as we proceed from west to east: the great gneiss zone of the Atlantic coast, which we call the zone of the Lofoten, then the table-land, which in spite of its poverty in organic remains has been proved to belong to the Cambrian system, in part even to the lower Silurian, and finally the Archaean land on the east. The western boundary of the table-land is a fracture, the eastern corresponds to normal superposition.

Towards the south the line of the Lofoten abandons the direction of the coast, but the investigations of Pettersen show that the masses of gneiss and granite, of which the Lofoten islands consist, are also present on the east side of the Vest fjord, and this great trough has been faulted down into the rocks of the Lofoten, the so-called 'coast-granite.' Further to the east, on the mainland, we find the same stratified rocks as we have just encountered about lake Torneå and the Bals fjord, but here they are folded. Gneiss and a long band of granite (the Kjölen granite) crop out in the anticlinals. The folds strike nearly parallel to the coast; they form the mountain of Sulitjelma; they are intersected transversely by the fjords, as for instance by the Salten fjord. *Here therefore a folded region lies between the range of the Lofoten and the table-land* [3].

Further to the south the folded region forms the Atlantic coast almost as far down as the mouth of Hardanger fjord (lat. 60° N.). It here consists, apart from intrusions of eruptive rocks, partly of beds of the same

[1] L. von Buch, Reise durch Norwegen und Lappland, II, Berlin, 1810; Gesammelte Schriften, edited by Ewald, Roth und Eck, 1870, II, pp. 449-453 and the section pl. v.

[2] Tellef Dahll, Om Finmarken's Geologi; Forh. Vid. Selsk. Christiania, 1868, pp. 213-222, pl. iv. T. Dahll rightly recognizes here the equivalents of the Cambrian alum shales; he regards the overlying beds as Devonian, the graphite beds as altered Coal-measures of the Carboniferous period, and the brown sandstones, superimposed on these, as Permian; no fossils have so far been found.

[3] Pettersen, Vestfjorden og Salten; Arch. Math. Naturvid., 1886, XI, pp. 377-492, map.

age as those of the table-land (as is proved by the Silurian fossils found in many places), and partly of the rocks which underlie these beds.

The two transverse sections so far published, as for instance that of Trondhjem by Meraker[1], scarcely enable us as yet to form any definite opinion as to the direction in which tangential force has acted: but the laborious surveys of this extensive and sparsely populated mountain region accomplished by Kjerulf and his fellow workers show clearly that the folds strike down from the north towards the south-west into the immediate neighbourhood of that part of the country which projects furthest to the west, the promontory of Stat (lat. 62° 10′ N.), without however following exactly the course of the coast. Towards the south, indeed, according to Kjerulf's map, the folds appear to turn more and more to the west, so that the Vigten islands, and next, with a more westerly trend, the great islands to the south outside the Trondhjem fjord, indicate the strike of the folds as they pass out to sea, and the more south-westerly course of the coast towards Stat appears equally to correspond with a swerving of the folds. Just above Stat promontory, however, an unexpected deflexion occurs. The principal band of gneissose granite, which comes down from the north-north-east in the direction of the Vartdals fjord, runs to the Vanelvs fjord, then bends up towards the north-west, and so reaches with this direction Stat promontory and the island of Sandö[2]. This is the beginning of a change in direction. To the south of Stat the strike is due west, and correspondingly the fjords also here assume an east to west direction; till finally, still further to the south beyond the Sogne fjord, the folds which appear on the coast strike into the interior, describing a semicircle around the neighbourhood of Bergen, and to the south of Bergen they reach the sea for the second time.

In its southern part, this semicircular curvature has been described in great detail by H. Reusch[3]. It is not a curvature with torsion like the

[1] T. Kjerulf, Merakerprofilet, K. Norsk. Vid. Selsk. Skr., 1882, pp. 63-140, 7 pl.; F. Svenonius, Några profiler inom mellersta Skandinaviens Skifferområde, Geol. Fören. Stockh. Förh., 1885, VII, pp. 631–653, pl. xvii. Fossils from these regions have been described by Brögger, Om Trondhjemfeldets midlere Afdeling mellem Guldalm og Meldalen; Forh. Vid. Selsk. Christiania, 1877, no. 2, pp. 1–28, pl. and maps.

[2] Hans H. Reusch, Grundfjeldet i söndre Söndmör og en Del af Nordfjord; Forh. Vid. Selsk. Christiania, 1878, no. 2, pp. 1–18, map.

[3] Hans H. Reusch, Silurfossiler og pressede konglomerater i Bergensskifrene, Universitets Program for 1 Halvaar 1883, 8vo, Christiania, 1882; by the same, Die fossilienführenden krystallinischen Schiefer von Bergen in Norwegen, translated into German by Baldauf, Leipzig, 1883. These investigations have furnished excellent examples of the extreme alteration of the rock by pressure and of the preservation of fossils in such rocks; they exactly correspond with observations made in the Alps. I was, however, much struck by the fact that in the flat-bedded parts of Norway also, particularly in the north, mica schist and hornblende schist occur, as has been already mentioned by many writers, and that in the Tromsö district for example, as Pettersen

great Roumanian arc on the lower Danube (I, p. 482), and indeed I know of no other example of the same kind. To the south of it, on the Hardanger fjord the folds terminate, and the horizontally stratified belt extends to Stavanger.

The way in which the folded ranges strike out to sea, in particular the bending round near Stat, the westerly strike of the folds south of Stat, and the lie of the Bergen arc, show that the continuation of these mountains lies to west and south-west beneath the sea. The direction of the structural features in west Scandinavia points towards the Shetland and Orkney islands, but the discussion of the remarkable correspondence which exists between Scotland and the mountains of Norway may be postponed to a later occasion.

3. *Glint lines.* On both sides of the Atlantic Ocean, to the north-west and to the north-east, there lies a vast region of Archaean rocks, from which the sedimentary covering, except for a few isolated patches, has been removed by erosion. In each of these regions there lies a shallow sea, on one side Hudson bay, on the other the Baltic. Each region is surrounded as with a rampart by the basset edges of the sedimentary formations, elsewhere swept away; these sediments everywhere belong to the older divisions of the Palaeozoic period, at latest to the Devonian, and round both shields they lie flatly bedded. In Russia the feature formed by these basset edges is known as the *glint*, and we shall in future employ this term for long lines of escarpment formed of flat-lying beds, when they are due, not to fracture, but to denudation[1].

The glint of each of the two shields is marked by a long series of fresh-water lakes, which lie in its course.

The glint lakes around the Canadian shield are: Ontario, Georgian bay, lakes Superior, Winnipeg, Athabasca, Great Slave lake, Martyr lake, Great Bear lake; the glint line then runs out into Coronation gulf, which is situated like a glint lake.

The glint line of the Baltic shield runs close to the east coast of Sweden

rightly observes, the lowest of these beds show the least alteration. Indeed, I have seen at the southernmost end of the Bals fjord, near the place where the great flexure (Fig. 6, pp. 58, 59) reaches the sea, many signs of striation and gliding on the bedding planes, and have found in some places, as at the bottom of the Dividal itself, partings in which the layers are plicated into themselves, as it were, although the other beds have remained horizontal; we may thus conclude that during the formation of so great a flexure there occur such tensions and interior movements of the beds one over the other that great alteration of the rocks may be produced without any real folding; but there are vast regions where such flexures do not occur, and yet through nearly the whole length of the peninsula crystalline schists are known at a higher level than deposits which are undoubtedly of Cambrian age.

[1] The outcrops described by Zittel in the Libyan desert are glint lines, produced by abrasion; the declivities at the south foot of the Uinta, which were produced by flexures, are not so.

not far from Kalmar, then through the sea north of Gothland, north of Dagö, through the gulf of Finland, which also has the position of a glint lake, through lakes Ladoga and Onega, into the gulf of Archangel and so to the Arctic Ocean.

A closer inspection of the structure of the Scandinavian peninsula shows that, in the north at least, north of Jemtland or of lat. 64° N., the eastern face of the table-land with its slightly inclined bedding, its bastions and ancient glacier portals, forms part of the Baltic glint. Just as, many years ago, Richardson and Isbister in north Canada remarked with astonishment the presence of so many lakes on the Palaeozoic boundary line, so, many years ago Törnebohm observed here that most of the great lakes of Lapland are intersected by this line of escarpment[1]. Indeed, all these great lakes, such as Hornafvan, Saggat Träsk near Kvikkjokk, Luleå Jaur, Paitas Jaur, Torneå Träsk, Alte Vand and Ruosta Vand, must be regarded as a series of glint lakes. The glint rises higher here than elsewhere, and the transverse position of the lakes is more strikingly shown than in any other region of similar character. The majority of these lakes find an outlet for their waters into the gulf of Bothnia, the remainder into the Atlantic Ocean, but this is a point which we need not consider at present.

The glint line is continued through the north of Finmark to the end of Varanger fjord, and through this to the Arctic Ocean.

From the foregoing, we perceive that there are not only glint lakes, but also glint gulfs of the sea. Such are: the gulf of Finland, the gulf of Archangel, Varanger fjord and Coronation gulf. Of these four gulfs, three belong to the Arctic Ocean.

4. *The table-land of Spitzbergen.* The Russian chain of lakes reaches the Ocean in the gulf of Onega and the White sea, immediately to the west of the peninsula of Kanin, the relations of which with the Ural range have already been discussed.

We have already learnt that Nova Zembla is a mountain chain folded to the west and north-west, which joins the Ural near Konstantinov-Kamen in lat. 68° 29′ N. (I, p. 504), the shar of Jugor, the straits of Kara, and the Matotshkin shar are transverse furrows, and the Kara sea is a 'back-sea" (Rückmeer). The Timan range, a divergent fore-fold or parma of the Ural, unites in syntaxis on the Sula with a little fragment of an arc, which strikes from the north-east of the Tshesskaja bay across the peninsula of Kanin towards Kanin Noss (I, p. 505)[2].

[1] Törnebohm, Geognostik schwedischer Hochgebirge, p. 49.

[2] A. Wichmann has expressed doubt as to Höfer's conception of the structure of Nova Zembla; but since Wichmann himself regards the island as the direct continuation of the island of Waigatsch and of the Pae-choï, this settles the chief question. I have recently rediscussed the matter with Herr Höfer, and am the more convinced that his

We have thus good reason to suppose that the valley of the Petchora, the floor of which is formed in great part of flat-lying Jurassic beds, stretches across the flat island of Kolguev to be continued beneath the south-east part of the Barents sea: this gives all the more interest to a knowledge of Spitzbergen, Franz-Josef Land, and Bear island.

Those who, like Nordenskjöld, Mohn and Nathorst, are best acquainted with these regions, have conjectured that a connexion once existed between Spitzbergen and the north of Norway; and Pettersen, who has brought together all the observations relating to this subject, distinguishes the table-land, or the group of great islands which may once have occupied the site of the existing Barents sea, as the 'Arctis[1].'

It is to the west of the Lofoten islands, on the Vesteraals-Eggen, that the sea first sinks to considerable depths along the Norwegian coast, as has been shown with great clearness by Mohn. The steep submarine slope runs thence to the north, towards the west coast of Spitzbergen. Barents sea lies above it, outside and to the east of the great depths of the Greenland sea, which sinks between Norway and the recent volcanic island of Jan Mayen to below 2,000 fathoms, and between Spitzbergen and Greenland to below 2,600 fathoms. Barents sea is thus of trifling depth; a furrow about 200 to 300 fathoms deep runs up between Norway and Bear island, and this is its deepest part; the hundred fathom line, however, runs from the Murman coast towards Nova Zembla, then from the north-west part of this island to the west and includes Bear island; so that the islands mentioned above, extending from Spitzbergen to Franz-Josef Land and to Bear island, form the highest parts of a single continuous plateau.

The results published by the Norwegian North-sea expedition show besides, that lying on the submarine slope which descends to the great depths from lat. 65° 36′ to 68° 21′ N., and in isolated localities even up to lat. 78° N., there are some residual fragments of Cretaceous, although deposits of this system are not known at present on the neighbouring land. These consist of pieces of chalk and flint; in lat. 65° 43′ N., long. 7° 29′ E. a fragment of a Belemnite was obtained from a depth of 194 fathoms. These fragments either prove the existence of a submarine Cretaceous belt, or excessive denudation of the surrounding land[2].

Let us now turn our attention first to the archipelago of *Spitzbergen*. Through the great kindness of Professor Nathorst, of Stockholm, I am able to make use of his comprehensive, and, as yet, unpublished observa-

views are correct since they fully accord with what we know of the structure of the north Ural; A. Wichmann, Zur Geologie von Nowaja-Semlja, Zeitschr. deutsch. geol. Ges., 1886, XXXVIII, pp. 516–550.

[1] K. Pettersen, Arktis, II; Arch. Math. Naturvid. Kristiania, 1882, pp. 465–489.

[2] H. Mohn, Dybde-Kart over Nordhavet; Norske Nordhavs-Expedition, 1887, XVIII, pl. i.

tions on the stratified series and the structure of Spitzbergen. The following description is derived from communications he has kindly made

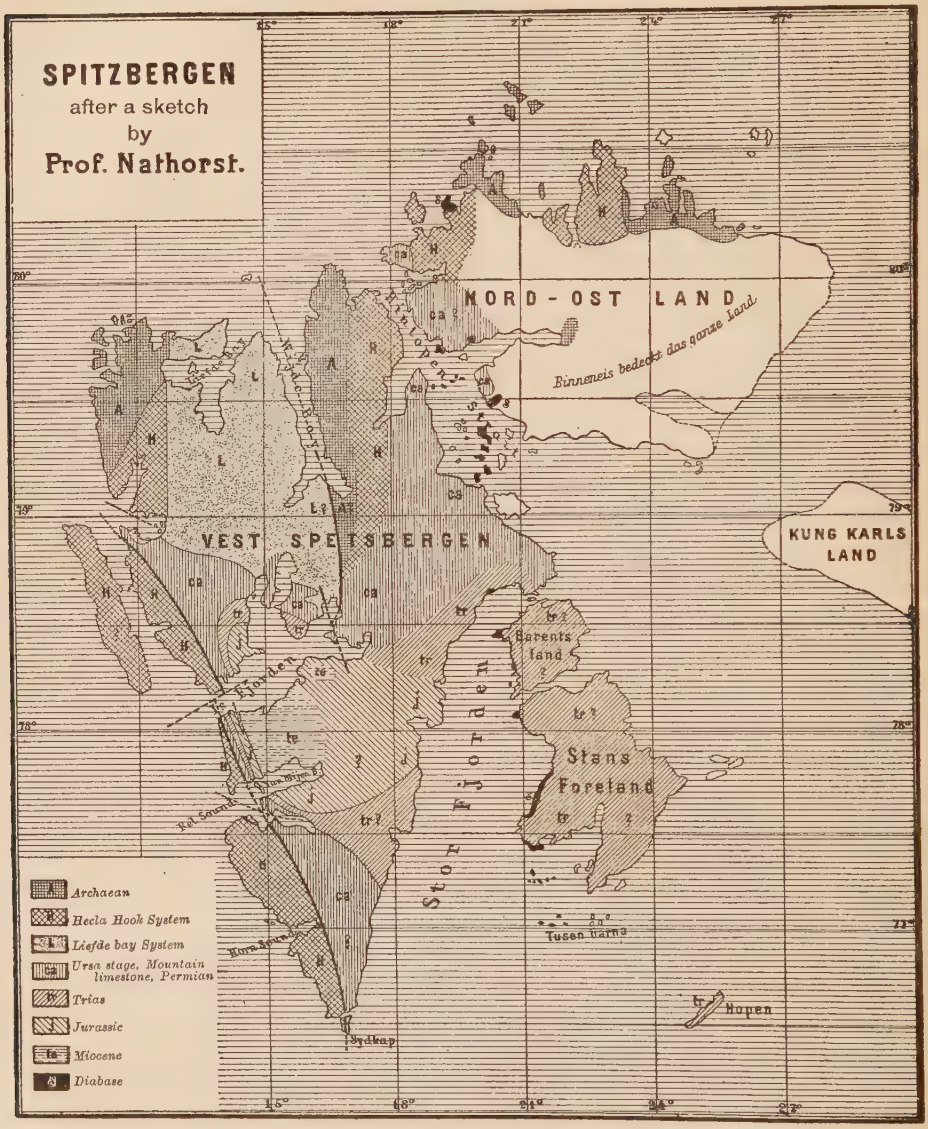


FIG. 8. *Spitzbergen.*

me by letter, and affords a more complete picture than the valuable works of Nordenskjöld, Höfer, Drasche, and others[1].

[1] In particular, A. E. Nordenskjöld, Spetsbergen's Geologie, K. Svenska Vet. Akad. Handl. Stockholm, 1867, VI, with geological map, also an English translation in the

According to Nathorst the stratified sequence of Spitzbergen is as follows:—

The Tertiary deposits consist, in the first place, of about 500 feet of lacustrine sediments with coal and land plants; beneath these lie 2,500 feet of marine sandstone, clay, and other beds, with marine mollusca, and finally another 100 feet of coal and plant-bearing beds.

Beneath these Tertiary beds a gap occurs with unconformity, then comes the Jurassic series, first, marine beds with Leda, Nucula and others, and then lacustrine beds with plants and fresh-water mollusca (once erroneously believed to be Cretaceous); next, marine beds with Ammonites; again, limnic beds with coal and plants; below these again, sediments which are perhaps marine. The Jurassic rests conformably on marine sediments, also completely conformable among themselves, of the Trias, Permian, and Permo-Carboniferous; the last of these rests also conformably on the Ursa stage, which contains plant remains, but in one locality it also exhibits an intercalation of marine sediments.

The Ursa stage rests unconformably on the Devonian series of Liefde bay, which contains Cephalaspis, Scaphaspis, and plant remains of the Old Red sandstone: in this series also a marine bed is probably intercalated.

The Devonian rests unconformably on the much older Hecla Hook system, which has not as yet afforded fossils; it consists of quartzite, phyllites, limestone, and dolomite, and close to it there occur granite, gneiss, and hornblende schists, which are said to represent the Archaean foundation, though Nathorst does not consider this definitely established. The Hecla Hook rocks which I saw in Stockholm resemble the phyllites of the eastern Alps.

Of the more recent eruptive rocks only diabase occurs; it traverses the beds as far as the Trias, in places even to the Jurassic. The largest masses of diabase occur in a zone running from south to north, which extends from the Thousand islands along the Star fjord far into the straits of Hinlopen.

The dislocations resulting from tangential stresses are confined to the fundamental rocks, and the Hecla Hook beds. These are, as a rule, steeply upturned, and form the sharp jagged mountains to which the highest peaks of Spitzbergen, such as the Hornsundstind, belong. All the other deposits, however, from the Devonian upwards, retain, except on the west side of Spitzbergen, a horizontal or only gently inclined position, save for some local and insignificant disturbances. The whole of the country formed by them is table-land.

Geol. Mag., 1872; H. Höfer, Graf Wilczek's Nordpolfahrt im Jahre 1872, I.: Beiträge zur Geographie Süd-Spitzbergens, Peterm. Mittheil., 1874, pp. 220–223; R. von Drasche, Geologische Beobachtungen auf einer Reise nach den Westküsten Spitzbergens im Sommer 1873, Verh. k. k. geol. Reichs, 1873, pp. 260–363.

Along the west side of Spitzbergen there runs a long horst which, towards the east, is separated from the island by a great line of fracture. On this line the sedimentary beds are steeply upturned or even inverted; according to Nathorst the feature must be regarded as a fault with down-throw to the east accompanied by upward flexure. The throw of the dislocation must amount to several thousand feet, since on the Ice sound, where the flexure is most widely extended, even the Tertiary beds are affected; the same is the case in King's bay. In Bel sound the upturning appears to terminate with the Trias.

The greater part of Spitzbergen is thus a table-land, and the same would seem to be true of Barents Land, Edge island, and Hope island, since all the beds of these islands appear to lie horizontal.

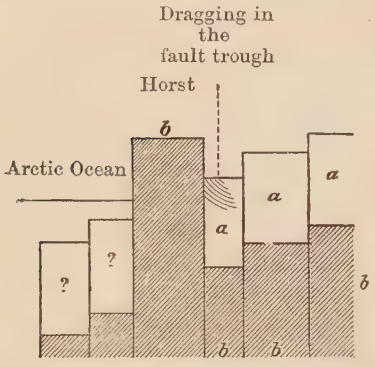


FIG. 9. *Diagrammatic representation of the Structure of west Spitzbergen* after Nathorst.

Another great fault runs down through Wijde bay towards Klaas Billen bay. This disturbance is, however, certainly very ancient, even older than the Ursa stage, since, west of Klaas Billen bay, beds of this stage lie flat on the Devonian, which is somewhat steeply upturned against the fracture, and to the east of this bay they rest immediately on the fundamental rocks still retaining their flat bedding. In Liefde bay, Klaas Billen bay, and Dickson bay, Nathorst found the Devonian everywhere horizontal, and the whole Devonian table-land appeared to him to be let down in an old pre-Carboniferous fault-trough.

It thus appears that faults are present of very different age; some are pre-Carboniferous, while others are post-Tertiary, and have produced an upward flexure of the Tertiary beds.

The throw of another fault, situated in Bel sound, along the north coast of Van Keulen's bay, must, according to Nathorst, amount to at least 2,000 feet, for beds of Carboniferous limestone are exposed both in the mountain peaks and on the seashore below.

Other faults of trifling importance also occur, some of which coincide with the lie of the fjords.

These main lines of the structure appear in the little map, Fig. 8, reduced from a sketch which Professor Nathorst was kind enough to send me. The ancient Hecla Hook rocks form almost the entire west coast, probably also Prince Charles promontory; the Archaean foundation makes its appearance in the north-west. Between Liefde bay and Wijde bay the Devonian is exposed, bounded on the east by the fracture, and on the whole north coast the ancient rocks of Hecla Hook and the Archaean are visible.

The centre of the country and the whole eastern part from the South cape to beyond Edge island is occupied by later sediments, and by the Mesozoic exposures of diabase.

It is extremely likely that the eastern islands are the continuation of the Mesozoic table-land in which Stor fjord lies.

As to *King Charles' Land* Nathorst observes that the only fossil so far known is a fragment of fossilized wood, described by Schröter as *Larix Johnseni*, and believed to be Miocene; that Tertiary beds occur here is certainly possible, but in Spitzbergen a conifer is found which probably belongs to Larix, and this occurs in the upper Jurassic.

In *Franz-Josef Land* the bold sledge journey of Payer has made us acquainted with horizontal sheets of eruptive basalt, and the more recent investigations of Leigh Smith have still further extended our knowledge. In Eira harbour (lat. 80° 10′ N. Franz-Josef Land, S.W.), Grant, who accompanied Leigh Smith, found that the cliff, 1,040 feet in height, is formed at its base of Oxford clay with Belemnites. Above this follow beds with coniferous wood and cones, and other plant remains; they are believed to be Cretaceous. The whole is covered with a sheet of basaltic lava[1].

Let us now turn our attention from Spitzbergen to the south.

Bear island consists of horizontal beds of Permo-Carboniferous age, and the Ursa series. Nordenskjöld met here with the Hecla Hook rocks; according to Nathorst it is uncertain whether these are exposed by erosion or by a prolongation of the great line of fracture which runs along the west side of Spitzbergen. The island is nothing but a fragment of the Spitzbergen table-land; Mohn has given a vivid account of the unceasing attack of the breakers on these horizontal beds, the undermining of the cliffs, the formation of great clefts, and the slipping down of mighty masses of limestone; such fallen masses, standing in isolated pillars or towers at the end of flat tongues of land, often remain to bear a long-enduring testimony to the destructive violence of the waves[2].

Thus we find repeated on this island that castellated form of the cliffs which has been so often described as characterizing the Palaeozoic limestone beds, likewise horizontal, of the North American archipelago, e.g. in the Parry islands and Lancaster sound. There we found arms of the sea running up in many ramifications between the islands of the archipelago, like a submerged system of river courses. We can indeed picture to ourselves how, with a rising strand-line, the sea will penetrate into the valleys of a horizontally stratified land, how it will widen them by under-

[1] C. R. Markham, The Voyage of the 'Eira,' and Leigh Smith's Arctic Discoveries in 1880; Proc. Geogr. Soc., London, new series, III, 1881, p. 135. According to Carruthers the conifer is a true pine. Etheridge mentions still older rocks beneath the Jurassic; tom. cit., p. 147.

[2] Norske Nordhavs Expedition, V, 1882; H. Mohn, Geografi og Naturhistorie, p. 32.

mining their banks, and so produce outlines which, as soon as the secondary watersheds have been crossed or destroyed, may come at last to resemble and not remotely those of the Parry archipelago. In the same way Bear island is regarded by most observers simply as an outlier of the great table-land, separated by erosion. Thus the sea completes the work which the rivers had begun, and in this way are accomplished those extensive abrasions to which the stratified succession of so many lands bears witness.

5. *Greenland.* The fundamental features of the stratified succession in Spitzbergen are repeated in Greenland, but only on the east coast and a part of the south-west. This correspondence has often been remarked upon by competent observers. Here as there, red sandstone rests horizontally and unconformably on ancient folded rocks, and the folding is thus older than the sandstone. In Greenland the red sandstone has not as yet furnished any organic remains, but it may doubtless be correlated with the Liefde bay series of Spitzbergen. The Mesozoic and Tertiary deposits also lie flat, as in Spitzbergen. This is the constitution of the great peninsula in the east, so far as the inland ice and the inhospitable nature of the coast have permitted us to become acquainted with it; in the west the characters of an abraded table-land are continued far to the north, probably about as far as the Humboldt glacier, where, as we have already seen, the upturned Silurian strata extend from Norman Lockyer island (lat. 79° 25′ N.) in Scoresby bay across Smith sound with a north-easterly strike (II, p. 42).

Greenland, as far north as Humboldt glacier, is probably an ancient table-land, yet it differs in some respects from the Canadian and Baltic table-lands, for in these two regions we meet with horizontal Silurian beds of marine origin, while in Greenland as in Spitzbergen the series of flat-lying beds does not begin, according to the present state of our knowledge, before the red sandstone.

Payer and Copeland have explored the east coast between lat. 73° and 76° N.; the facts brought together by Hochstetter and his fellow workers show that the greater part of the coast of the mainland, together with most of Clavering island and Kuhn island and the north of Shannon island, consists of Archaean rocks. Ancient quartzite, clay slates, and limestone, which are assigned to the Hecla Hook series of Spitzbergen, are exposed on the north coast of Franz-Josef fjord. In False bay (Clavering straits, west of Sabine island) Payer made the remarkable discovery of Rhaetic fossil, *Rhynchonella fissicostata*, the only representative of this series found as yet in the Arctic regions. On Kuhn island there are Jurassic deposits similar to those of Spitzbergen, and similarly associated with coal and plant-bearing beds. Basalts and plant-bearing sediments of middle Tertiary age crop out for a great distance along the coast from

the little Bontekoe islands in front of Franz-Josef fjord, northwards up to the middle of Shannon island, so that all the land which runs farthest out to sea—such as cape Broer Ruys, cape Borlase Warren, Sabine and Pendulum island, and cape Philip Broke on Shannon island—belongs to the basalt region. Hochstetter foreland also is middle Tertiary: it has furnished remains of Tertiary marine mollusca similar to those of Spitzbergen. I may observe that these are the only two regions in the Arctic Ocean which have afforded marine Tertiary fossils. The basalts of Iceland, the Faeroës, and even Ireland (so far to the south) and the west coast of Greenland are everywhere accompanied by Tertiary beds which contain no other fossils than terrestrial plants[1] (I, p. 287).

The west of Greenland, from cape Farewell to lat. 61° N., consists mainly of granite, beside which gneiss appears only in isolated localities—according to Laube on the precipitous cape Whitsuntide on the east coast, and on Sermersoak in the south-west. On the east coast the granite frequently contains hornblende; on the west, according to the recent investigations of Steenstrup and Kornerup, it is traversed north of Igaliko fjord by a mass of syenite, and north of Julianehaab, at the mouth of the Tunugdliarfik, by a mass of sodalite syenite, which is cut right through the middle by the fjord. A great mass of red sandstone, accompanied by porphyry, separates, north of the sodalite-syenite, the Sermilik from the Tunugdliarfik fjord, and extends across the latter to the north end of the Igaliko fjord. So far the red sandstone, as we have already mentioned, has not afforded any organic remains[2].

In the interval between lat. 62° 15′ and 64° 15′ N. Kornerup encountered only Archaean rocks, chiefly grey gneiss. Its strike is generally directed to the north-east[3].

The land much further to the north also, between lat. 66° 15′ and 68° 15′ N., was found by the same observer to be formed of different

[1] F. v. Hochstetter, Geologie Ost-Grönlands zwischen dem 73. und 76.° n. Br.: *a.* Allgemeine Uebersicht, bearbeitet von Franz Toula, *b.* Specielle Darstellung, bearbeitet von Oscar Lenz; Mesozoische Versteinerungen von der Kuhinsel, von Franz Toula, in Zweite Deutsche Nordpolfahrt, II, 1872, pp. 471–511, and Hochstetter, Geologische Kartenskizze von Ost-Grönland nach den Beobachtungen und Sammlungen von Payer und Copeland, op. cit., pl. i. All the earlier geological literature of Greenland is given in Rupert Jones' valuable manual of the Natural History, Geology, and Physics of Greenland, 8vo, London, 1875.

[2] Gustav Laube, Geologische Beobachtungen gesammelt während der Reise des 'Hansa' und gelegentlich des Aufenthaltes in Süd-Grönland, Sitz. k. Ak. Wiss. Wien, 1873, LXVIII, pp. 17–109, and geological map; K. J. V. Steenstrup og A. Kornerup, Beretning om Expeditionen til Julianehaab's Distrikt i 1876, Meddels. om Grönland II, Kjöbnhavn 1881, pp. 1–26; Steenstrup, Bemærkninger til et geognostik Oversigtskaart over en Del af Julianenhaab's Distrikt, op. cit., pp. 27–41, and geological map.

[3] A. Kornerup, Geologiske Iagttagelser fra Vestkysten af Grönland (lat. 62° 15′–64° 15′ N.); Meddels. om Grönland, I, 1879, pp. 77–139, geological map B.

varieties of gneiss, and this great mass of gneiss, lying in folds striking to the north-east, appears to form by far the larger part of the west coast[1].

Between lat. 70° and 72° 39′ N. and beyond, the same Archaean rocks crop out at the edge of the inland ice, but in front of them, towards the sea, lie great basaltic regions, such as we have already studied on the east coast from the mouth of Franz-Josef fjord up to Shannon island. I may cite as examples taken from the latest surveys of Steenstrup, Disko island (on the south and south-west coast of which the Archaean foundation is visible), then Hare island, the peninsula of Nugsuak, Ubakjendt island, the peninsulas of Svartenbuk and Ingnerite. On this side as in the east, the Archaean region of the interior is bounded by a basaltic belt, and it is beneath these mighty sheets of lava that those rich Cretaceous and middle Tertiary floras are preserved which have furnished the most important material for the investigations made by Oswald Heer on the Arctic floras of the past[2].

A fact of great importance in its bearing on questions to be discussed later is the discovery made by Steenstrup of the presence of marine Cretaceous fossils within this series of beds which, except for some local disturbances, are always horizontal. The succession, according to the present state of our knowledge, is as follows:—(1) *Kome* beds, resting directly on gneiss, and containing a terrestrial flora of lower Cretaceous age; (2) *Atane* beds, with a terrestrial flora of Cenomanian age, corresponding to that of the Quader sandstone of Central Europe, and containing several species of the flora of the Dakota stage in America; (3) *Patoot* beds, containing a terrestrial flora of Senonian age, and also, up to 1,200 feet above the existing sea-level, Cretaceous marine fossils. Loriol has established their affinity with the Fort Pierre and Fox Hill beds of Nebraska[3]. Above these lie the Tertiary plant-bearing beds, and the great basaltic sheets which reach a height of more than 5,000 feet above the existing sea.

The Cretaceous marine beds are known in the south of the peninsula of Nugsuak, and also in the north up to about lat. 70° 45′ N. Thus far therefore the Senonian sea had penetrated. We mentioned a patch of marine Cretaceous on the Mackenzie in lat. 65° N. and the fossils of Patoot point clearly to a connexion with the Cretaceous sea of the North American prairies. Although we shall scarcely be able to determine how far the Cretaceous sea once extended to the east, over the abraded Canadian

[1] A. Kornerup, Geologiske Iagttagelser fra Vestkysten af Grönland (lat. 66° 55′–68° 15′ N); op. cit., II, 1881, pp. 151–208, geological map, pl. vi.

[2] K. J. V. Steenstrup, Bidrag til Kjendskap til de geognostiske og geografiske Forhold i en Dal af Nord-Grönland, Meddels. IV, 1883, pp. 173–242, geological map; and by the same, Om Forekomsten af Forsteninger i de Kulförende Dannelser i Nord-Grönland, op. cit., V, 1883, pp. 45–77.

[3] P. de Loriol, Om fossile Saltvandsdyr fra Nord-Grönland; tom. cit., pp. 203–213.

table-land (I, p. 558), yet in the extreme north we recognize it in isolated traces beneath the basaltic sheets.

The earlier observations of Sutherland, who was already acquainted with the basalts from Disko up to Proven island in lat. 72° 20′ N., show that the coast to the north of Proven island, as far as cape York in lat. 76° N., consists, together with the bordering islands, almost exclusively of gneiss and granite. North of cape York up to cape Atholl, i.e. for a distance of about 30 to 40 knots, basaltic outflows, probably the same as those of Disko, again make their appearance [1].

Cape Alexander at the mouth of Smith sound consists of basalt, and this again is followed to the north by gneiss; the rest of the east coast of Smith sound towards the Humboldt glacier appears to be unknown [2].

Along this great ice stream or close to its further side, the folded ranges with Palaeozoic fossils begin. The Tertiary lignite beds also extend into this region, and were encountered by Feilden in Grinnel Land, at Discovery harbour in lat. 81° 45′ N. [3]

Great as is the variety of sediments on the west coast of Greenland, yet as far north as the Humboldt glacier the only beds which have so far afforded marine fossils are the Senonian intercalations of Patoot; a striking contrast to the east coast, where indeed the Cretaceous formation has never yet been encountered, neither has it been met with in Spitzbergen.

6. *The Caledonian mountains.* 'The Scottish Highlands, with the Hebrides and Donegal on the one hand, and the Orkneys and Shetlands on the other, must be regarded—to use a technical phrase—as mere "outliers" of the Scandinavian peninsula.' So writes Judd, one of the geologists best acquainted with the country; and other distinguished investigators, such as A. Geikie, hold the same view [4]. This conception of the Scotch geologists rests, it is true, primarily on the correspondence between the stratified series of the two regions. The Torridon sandstone, an arkose, or sandstone containing feldspar, which underlies the Cambrian, is correlated with the sparagmite of Norway. A. Geikie is inclined to think that the zone of Old Red sandstone, which has been traced along the Moray firth through the east of Ross and Sutherland, then through Caithness to the Orkneys and into the southern part of the Shetland islands, may once possibly have

[1] P. C. Sutherland, On the Geological and Glacial Phenomena of the Coasts of Davis' Strait and Baffin's Bay; Quart. Journ. Geol. Soc., 1853, IX, p. 297. I have not ventured to quote the observations made north of cape Atholl, since they are rather indefinite and evidently made from the ship.

[2] The little map by Feilden and de Rance in Quart. Journ. Geol. Soc., 1878, XXXIV, pl. xxiv.

[3] O. Heer, Notes on Fossil Plants discovered in Grinnell-Land by Capt. H. W. Feilden; tom. cit., pp. 66–70.

[4] J. W. Judd, Address to the Geological Section of the British Association at Aberdeen, 1885.

extended into the Sogne fjord and Dals fjord, where similar red conglomerates have been met with, although so far without organic remains [1]. Judd points out the striking resemblance that exists between the Mesozoic deposits of Scania and those rare patches of the same age in Scotland, which have been preserved by great subsidences or beneath sheets of basalt. In both regions the series begin with Trias sediments (containing reptiles in Scotland), and above this there follows a series of alternating marine and fresh-water deposits, the latter containing the remains of terrestrial plants; in both regions the lowest members of the Cretaceous are absent, and the higher members are alone represented. At Andö, in the Lofoten islands, the Jurassic no doubt owes its preservation to subsidence, as it does on the Scotch coast.

Our study of the Scandinavian peninsula has shown that it may be distinguished into several regions. The first is the Archaean zone of the Lofoten or the western zone of gneiss, which may be traced across the islands and peninsulas of the north, from Magerö to Vest fjord. The second region is the table-land of the north, separated by dislocation from the western zone of gneiss and terminating on the east with horizontal stratification in the glint, which runs down from the Varanger fjord. In the Rippe fjord, lat. 70° 30′ N., the dislocation along the western gneiss zone is a fault with upward flexure of the down-thrown table-land; at the bottom of the Bals fjord, on the other hand, in lat. 69° 10′ N. all the table-land appears to dip westwards in a great flexure beneath the gneiss zone, or at least beneath the band of gabbro which lies in front of it. Further to the south the table-land itself in its western part appears to be thrown into the long, south-south-west striking folds of the great Norwegian ranges, while to the east it always remains flat and runs out to the glint. East of the glint lies the Archaean table-land of the gulf of Bothnia; that is, the Baltic shield.

These fundamental features in the structure of the Scandinavian peninsula enable us to perceive that there exists in the two regions not only a correspondence between the stratified succession as shown above, but also a far-reaching correspondence in structure, and that the contours of the Atlantic from the North cape in lat. 71° 10′ N. to at least as far as Donegal bay in lat. 54° 30′ N. are formed by once continuous mountain ranges, constructed on a common plan.

A. and J. Geikie have shown in a number of highly instructive descriptions that the structure of Scotland is clearly expressed in the configuration of the surface, as well as in the character of the landscape. It also reveals itself in the plainest manner in the course of the coast lines [2].

[1] A. Geikie, Textbook of Geology, 8vo, London, 1885, p. 712.

[2] From this long series I will only quote the latest work known to me: J. Geikie, The Physical Features of Scotland, Scott. Geogr. Mag., I, 1885, pp. 26–41. For the con-

Scotland and the adjacent islands are represented in Fig. 10 on the same scale as that chosen for the sketch of Spitzbergen (II, p. 68, Fig. 8). We observe a continuous range of Archaean rocks in the north-west. The ancient gneiss is visible in the Hebrides, in the south-east of the islands of Coll and Tiree, in Raasay and Rona, and along the north-west coast of Scotland. In a precisely similar fashion the Archaean range of the Lofoten lies to the west and in front of the Scandinavian peninsula.

The Minch lies on the gneiss region in the same way as the Vest fjord does in Norway; some of the Tertiary volcanos of the Hebrides belong to the same region (I, p. 156, Fig. 19), and in particular the great basalt flows of Skye.

The Archaean area is bounded on the east by a zone of dislocations of a peculiar nature; beginning on lake Eriboll it is continued through loch Assynt and the upper parts of loch Broom and loch Maree as far as loch Carron, and no doubt still further to the south-south-west, on the inner side of the gneissose islands of Coll and Tiree. Murchison, deceived by the extraordinary position of the beds in the north part of this zone, came to the conclusion many years ago that the gneiss is here normally superposed on fossiliferous Silurian beds, and he consequently asserted the existence of a more recent Silurian gneiss as opposed to the ancient gneiss of the Hebrides. Nicol challenged Murchison's views, and thought that the superposition of the gneiss was due to great dislocations. This interpretation was revived by Bonney, Hicks, and Callaway, and found its strongest support in the brilliant discoveries of Lapworth[1]. To bring a long controversy to a close, A. Geikie, as the Director of the Geological Survey, commissioned Messrs. Peach and Horne to make an exact survey of the district around loch Eriboll and the extreme north-west of Scotland. As a result of this work, A. Geikie has now admitted, with the sincerity which distinguishes and honours the true man of science, the erroneousness of the older theory[2].

The section from the Kyle of Durness across loch Eriboll published by Peach and Horne reveals the following features:—

tinuation to Ireland, R. Harkness, On the Rocks of Portions of the Highlands of Scotland South of the Caledonian Canal and on their Equivalents in the North of Ireland, Quart. Journ. Geol. Soc., 1861, XVII, pp. 256–271; E. Hull, The Physical Geology and Geography of Ireland, 8vo, London, 1878, p. 20; C. Callaway, On the Granitic and Schistose Rocks of North Donegal, Quart. Journ. Geol. Soc., 1885, XLI, pp. 221–239 (Overfolding in Donegal, p. 238).

[1] H. Hicks, On the Metamorphic and overlying Rocks in parts of Ross and Inverness Shires, Quart. Journ. Geol. Soc., 1883, XXXIX, pp. 141–159 (Appendix: On the Lithological Characters of a Series of Scotch Rocks, &c., by T. G. Bonney, tom. cit., pp. 159–166), and map; C. Callaway, The Age of the newer Gneissic Rocks of the Northern Highlands, tom. cit., pp. 355–414 (Lithology in Appendix by Bonney, pp. 414–420); C. Lapworth, Close of the Highland Controversy, Geol. Mag., 1885, pp. 97–106 et passim.

[2] A. Geikie, The crystalline Rocks of the Scottish Highlands, Nature, Nov. 13, 1884, pp. 29–31, and B. N. P. Peach and J. Horne, Report on the Geology of the North-west of Sutherland, tom. cit., pp. 31–35. The correspondence of the Lofoten islands and the Hebrides is emphasized by Bonney, Quart. Journ. Geol. Soc., 1870, XXVI, p. 623.

FIG. 10. *A General Sketch of the Structure of Scotland* based on the Geological Map of Scotland, by Sir A. Geikie.

a Archaean ; *s* Silurian and ancient schists, together with included masses of Granite ; *d* Old Red sandstone, and *ca* Carboniferous, together with eruptive masses, whether Devonian or Carboniferous is still a matter of opinion ; *tr* Trias ; *J* Jurassic; Tertiary eruptive rocks are shown *black*. (The thrust-plane which forms the eastern boundary of the Hebridean gneiss is not completely indicated.)

In the neighbourhood of Durness, that is in the north-west, the Cambrian beds, probably 2,000 feet thick, folded and transversed by faults, rest upon the gneiss. Another range of gneiss advances towards the sea, and also bears in the east a patch of Cambrian. Then the country breaks up on the southern shore of loch Eriboll into numerous flakes of gneiss and Cambrian, the thrust-planes of which dip to south-east and east-south-east, and thus reveal a considerable tangential movement from this direction. Above these smaller flakes, and overthrust from this same direction, that is from the east-south-east, lies a mass of ancient gneiss, with a maximum thickness of 400 feet. This overlies, on a great plane of reversed faulting (thrust-plane of the Scotch geologists), all the various stages of the Cambrian one after the other, as they appear in succession in the smaller flakes. A patch of this overthrust mass of gneiss, separated from it by denudation, lies isolated on the Cambrian in the north-west of Ben Arnaboll.

East of Whitten head, at the mouth of loch Eriboll, there follows a second and yet vaster overthrusting of gneiss, which may be followed for many miles to the south-south-west—a second master-flake, so to speak, superposed on the first.

So far we have traced the overthrusts for a distance of 90 miles to the south-south-west, and an isolated exposure of gneiss over Cambrian in the west reveals a tangential movement of the great gneiss flakes to the extent of at least 10 miles. It is obvious that on these immense surfaces of movement a really extraordinary amount of gliding, grinding, scoring, rolling out and manifold alteration of the rocks must have occurred.

Above the edges of a system of smaller flakes, which assumes the form of a unilaterally compressed trough, other much larger flakes have been driven in an almost horizontal direction for a distance of at least 10 miles. The movement came constantly from the east-south-east. Such then is the appearance presented by the base of the outer border of a lofty mountain chain, when completely levelled down by denudation. The gneiss of the Hebrides lies in front of it, like Bohemia before the eastern Alps. All these great movements however are older than the lower part of the Devonian red sandstone, and fragments of the ancient mountain chain are included in the breccias and conglomerates of this formation.

This zone of overthrusting we will designate for brevity '*the Eriboll zone of overthrust.*' Judging from its lie and position it corresponds to the great dislocation which in the extreme north separates the table-land of Norway from the western zone of gneiss.

To the south-east of the Eriboll zone the Scotch highlands extend as far as a line of fracture which runs from near the mouth of the Clyde across the south part of loch Lomond, and then across the whole country, keeping a north-east direction till it reaches the east coast at Stonehaven.

This fracture sharply bounds the highlands on the south-east, and they are divided in the middle by a parallel fracture which runs from loch Linnhe right across the country, and is continued parallel to the north coast of the Moray firth. The first line marks the south border of the Grampians the second is the line of the Great Glen. The latter cuts so deeply into the country that it has rendered possible the construction of the Caledonian canal.

The two moieties of the Scotch highlands are formed principally of Silurian beds, thrown into folds which strike to the north-east, nearly parallel to the zone of Eriboll. These are the inner folds of the chain. The great fractures are therefore longitudinal fractures which run with the strike. On the eroded surface of these ancient mountains, on its slopes and in its hollows, lies the Old Red sandstone, preserved from destruction to the present day, in some places as originally superposed, in others owing to subsidence.

We see it, as it extends from the bottom of the Great Glen to the north-east, bordering both shores of the Moray firth, then broadening out over Caithness, and passing out to sea from this northernmost extremity of Scotland to form the Orkney islands. It is still visible on the south-east side of the Shetland group, and thence is continued, as Geikie believes, along the Sogne fjord or the Dals fjord.

South of the Great Glen granitic intrusions increase in number. In this region we find that the ridges which trend towards Ireland correspond in direction with the strike of the ancient formations which, as matter of fact, do indeed find their continuation in the north of that island. Finally, as we reach the Clyde, we encounter the faulted boundary of the highlands.

All the country south of this fracture, about as far as Girvan on the firth of Clyde and Dunbar on the firth of Forth, is known as the Central lowlands. This is the richest part of Scotland; here lie Edinburgh, Glasgow, and the coalfields. It is a trough; the southern edge is split up by numerous fractures, and consequently does not contribute so continuous a feature to the landscape as the northern edge. The trough is filled with subsided masses of Devonian red sandstone, and the various stages of the Carboniferous, which elsewhere have been swept away over vast areas, leaving exposed the Silurian horsts on the north and on the south. The constriction of Scotland between the firth of Clyde and the firth of Forth corresponds to the trough, while the horsts project to north-east and south-west into the sea. The subsidence would find yet clearer expression in the configuration of the land were it not that eruptive rocks, in particular porphyries, accompany the down-thrown sediments, and these rise in hills above their surroundings owing to the greater resistance they offer to denudation.

We will now pass to a consideration of the south edge of the trough.

On the south a second Silurian horst is seen, which recalls in many respects the highlands. The Lammermuir hills and the Moorfoot hills in the north-east belong to its outer part. Fractures are numerous, but not as it would appear continuous, and sinking movements have taken place here at various times. A few are certainly older, others just as certainly younger, than the Carboniferous period.

The principal fracture in the central region is overlaid and covered up towards the north-east by the Coal-measures of Midlothian. Along this fracture the whole thickness of the Old Red sandstone amounting to at least 15,000 feet is let down in the middle of the country. In this region the dislocation is certainly older than the Carboniferous of Midlothian, which rests, south-east of the fracture, directly upon Silurian; thus before the deposition of the Carboniferous limestone the Old Red sandstone was not only faulted down, but its whole thickness was removed by erosion. Nevertheless, subsequent movements have also affected the Carboniferous. At the same time, the fault in this region has so little effect on the surface of the country that it is crossed by several river valleys; and thus the Nith, a little river which rises in the southern Silurian horst, flows across the great fracture into the sunken region, makes a bend near New Cumnock in the Carboniferous, returns across the fracture into the Silurian and finally flows into the Solway, having thus completely traversed the southern horst[1].

Thus geology points to subsidences in the midst of the mainland which may attain in a single fault the mean depth of the Atlantic Ocean, and yet this fault manifests itself so little in the landscape that a mere thread of water such as the Nith pursues its winding course undisturbed across it.

In the north-east, on Dornoch firth and on the south side of Moray firth, patches of Mesozoic and in particular of Jurassic rocks occur close to the sea, separated by faults from the ancient highlands behind them. Judd has described these rocks in detail[2]. They are downthrown fragments; one of them forms the Jurassic coalfield of Brora on the coast of Sutherland. The lines of subsidence correspond here to the course of the coast and are almost parallel to the Great Glen. Where the line of the Great Glen itself is continued along the north shore of Moray firth to the sea, some downthrown patches of Mesozoic lie against it. Other patches lie on the south-east side of the same firth. In the highlands Mesozoic deposits have furnished abundant material to the ancient glacial débris, and on the west side, e.g. on Skye, they remain preserved from denudation beneath the basaltic sheets in patches of considerable size. Judd rightly

[1] Peach, Mem. Geol. Surv. Scotland; Explanation of Sheet 15, 8vo, 1871, pp. 7 and 37.

[2] J. W. Judd, The Secondary Rocks of Scotland; Quart. Journ. Geol. Soc., 1873, XXIX, p. 113 et seq., pl. vii (cf. I, p. 206).

concludes that they must once have covered the greater part of the highlands and that great subsidences must have occurred even after the Mesozoic period.

These downthrown patches of Mesozoic beds increase the resemblance of the highlands to the horsts of the Rhine, but we must observe that the subsidence faults in Scotland are true longitudinal faults in the direction of the ancient folding, while in the Vosges and the Black Forest the folds are cut through obliquely by the faults of the Rhine valley[1].

Shetland and the Orkneys, the Scotch highlands together with the trough of the lowlands, and the southern horst, must be regarded as the continuation of the folded mountains of Norway. The sea which separates Scotland from Norway lies on a downthrown segment of these mountains, as is shown by the mighty fractures of the Scotch coast. These pre-Devonian mountains, which proceed from Norway and form the whole of Scotland, together with their overthrust outer border along the zone of Eriboll, we call the *Caledonian mountains.*

In Scania many movements may be shown to have taken place after the Cretaceous period. In Scotland we observe subsidences, some of which are very ancient, and others which are post-Cretaceous, probably even post-Tertiary, in age; Judd indeed believes that the separation of Scandinavia from Scotland took place in comparatively recent times, perhaps even after the appearance of man. A curious fact may be cited in support of this view. Peach and Horne have found that the Shetland islands are everywhere polished by ice, and that the glacial striae cross the eastern side of the islands from the north-east, swing round to the north-west on reaching the central axis, and proceed in this direction across the western side of the islands to the Ocean. Thus a continuous sheet of ice coming from Scandinavia must have moved transversely across these islands[2].

The Caledonian mountains are continued through a great part of Ireland and Wales.

Ireland includes mountains of very various structure. In the north rise the ridges of Donegal, readily recognized as the prolongation of the mountains of Scotland, the strike is the same in both. They reappear in

[1] In this way Lepsius explains the subsidences of Saverne and in the Kraichgau; R. Lepsius, Die oberrheinische Tiefebene und ihre Randgebirge; Forschungen zur deutschen Landes- und Volkskunde, herausg. v. R. Lehmann, I, 2. Heft, 1885, p. 70. The fault-lines strike out along Dornoch and Moray firth in the same manner as those which proceed from the west border of the Bohemian mass towards Bavaria.

[2] B. N. Peach and J. Horne, The Glaciation of the Shetland Isles; Quart. Journ. Geol. Soc., 1879, XXXV, pp. 778–811, and geological map. The authors suppose that the sea between Scandinavia and the Shetlands was completely displaced by the ice mass.

Mayo and on the north side of Galway bay. In like manner the older formations crop out in the south-east of the island, again with the same strike to the south-south-west; they extend through Carlow, Wicklow, and Wexford, and their folding is prior to the deposition of the Old Red sandstone. These fragments of the pre-Devonian Caledonian mountains are united together by a broad platform of flat-lying Carboniferous limestone, from the surface of which the Coal-measures have in large part been removed by erosion; it is so flat that from Dublin in the east to Galway in the west there is scarcely an elevation which attains the height of 260 feet.

In the south of the island another range of mountains appears. This is younger; the Old Red sandstone and the Carboniferous limestone are here thrown into long folds, which strike from west to east, but are deflected in the south-west corner of the island to the west-south-west. The various anticlinals run out into the Atlantic in projecting spurs, while the synclinals form deep bays. These submerged synclinals follow one another in close succession in the bays of Dingle, Kenmare, Bantry, Dunmanus, and Crook, so that the outline of the south-west coast of Ireland is entirely determined by folding of the crust.

On the peninsula between Dingle bay and Kenmare bay an anticlinal of the Old Red sandstone rises in Macgillicuddy Reeks to form the highest peak in Ireland (3,414 feet). Near the lake of Killarney this anticlinal is completely overfolded to the north, so that the flat-lying Carboniferous limestone of central Ireland is found here together with pinched-in Culm beds, dipping to the south, beneath the Old Red sandstone.

These folds and overfolds in the south of Ireland also strike out to sea on the east coast of Cork and in Waterford. They are only a part of a great arcuate range, which is continued from here towards the east into Wales and England, and thence still further into Belgium [1].

This great arc, striking from east to west, and opposed in so marked a manner to the older Caledonian folds striking to the south-south-west, we will designate *the Armorican arc*: we here meet with its northern border for the first time: the contrast between it and the Caledonian folds is especially well seen in the south-east of Ireland, as in the counties of Kilkenny and Carlow.

Let us now return to the other side of St. George's channel. Moore has shown how in Wigtownshire, on the south-west coast of Scotland, the rocks of the Southern Uplands, thrown into steep folds, proceed towards the sea between Corswell lighthouse and the Mull of Galloway. In the north of this coastal region the greater part of the folds are overturned to

[1] Hull, Physical Geology and Geography of Ireland, p. 138. A section through Dingle, Kenmare, and Bantry bay, showing a great fracture in the first, and synclinals in the other two bays, is given by Kinahan, Geol. Mag., 1879, 2nd ser., VI, p. 351.

the north-west; in the south, on the other hand, to the south-east; so that an imbricated fan structure is produced [1].

In like manner the gneiss ridges of Anglesey strike across the island to the south-west, and are continued on the south coast of Carnarvon bay into the peninsula of Lleyn, which faithfully follows the Caledonian direction. These parts of North Wales belong, however, as shown by their strike, to a part of the Caledonian region lying further to the east than the ranges of Carlow and Wexford mentioned above; these, it is true, are followed in the extreme south-east of Ireland near Carnsore point, south of Wexford bay, by another small exposure of ancient rocks.

The folds of North Wales, like those of Carlow and Wexford, are older than the Old Red sandstone. From the north side of Anglesey the Carboniferous limestone extends in a great arc along the border of the folded region, so that throughout the east of Wales it rests on the various members of the Silurian formation; it is accompanied by a discontinuous band of Old Red sandstone which further south broadens out over a wide area in Hereford and Brecknock [2].

We have now reached South Wales, that region in which we may see, thanks to profound erosion, the encounter of the pre-Devonian Caledonian ranges, striking south-south-west to south-west, with the more recent post-Carboniferous Armorican folds, striking east to east-south-east. Here I follow principally the description given as early as 1846 by De la Bêche; this I cannot mention without an expression of deep gratitude to the author, now long since dead, since it exercised many years ago a decisive influence on my own views as to the structure of great mountain ranges. Although published forty years ago, this description is inspired by those conceptions of the formation of mountain ranges by lateral pressure, and of the true influence of granite masses, which are now winning their way step by step to general acceptance [3].

The boundary line between the Caledonian and Armorican regions may be recognized with comparative ease on any geological map, for the north border of the Armorican range coincides with the south border of the coal-field. Leaving Waterford in Ireland, the boundary line enters St. Bride's bay, Pembrokeshire, with a strike bent a very little from east to east-south-east, passes across the upper part of Caermarthen bay, then across Swansea bay to the broad estuary of the Severn which it reaches in the neighbourhood of Cardiff, it crosses the Severn and is continued on the

[1] J. C. Moore, On the Silurian Rocks of Wigtownshire; Quart. Journ. Geol. Soc., 1856, XII, pp. 359–366.

[2] A. C. Ramsay, The Geology of North Wales; Mem. Geol. Surv. Great Britain, vol. III, 1866, p. 13.

[3] Sir Henry T. de la Bêche, On the Formation of the Rocks of South Wales and South-west England; Mem. Geol. Surv. Great Britain, 1846, vol. I, pp. 1–296, in particular, pp. 221–239; cf. Entstehung der Alpen, p. 16.

north border of the Mendip hills. Thus it is only the southern part of the three promontories on the north coast of the Bristol channel which belongs to the Armorican folds. North of the boundary, the rich coal-fields of St. Bride's bay extend in the form of a narrow compressed zone to Caermarthen bay; this they cross, and attain on its further side a continually increasing breadth until they spread out in Glamorgan and Monmouth as the great coalfield of South Wales. This expansion corresponds to the retreating curve of the northern mountains—the continuation of the Caledonian hill-ranges of North Wales; these we must now consider in greater detail.

In North Wales we have already become acquainted with the typical Caledonian strike in Anglesey and the peninsula of Lleyn, and we have also seen that the Caledonian folding is older than the Old Red sandstone. The Caledonian folds are continued through Merioneth and are sometimes directed from north to south, but in Cardigan they make a bend to the south-west which becomes more and more marked towards the south, and beyond the town of Cardigan towards Fishguard they swing completely round into the Armorican direction, or from east to west; the beds are then very much disturbed both in a horizontal and vertical direction. Here, 'in the northern part of Pembrokeshire,' says De la Bêche, 'we may have the complicated forms resulting from a twist of the rocks in a new direction over an older one[1].'

St. David's head, which bounds St. Bride's bay on the north, consists, according to A. Geikie, of an anticlinal of Cambrian rocks, which strikes to the south-west, that is obliquely across the peninsula, and is overfolded to the south-east[2]. The predominance of a trend so entirely different from that of the Armorican folds is very remarkable. Towards the interior of the country, it is true, the overturned south-east side assumes a vertical position; but towards the head of St. Bride's bay, next the pinched-in band of Coal-measures, great fractures and disturbances occur in the Cambrian rocks[3], and it is not till we proceed further to the east, where the coalfields of Glamorganshire broaden out, that we first see with some distinctness a deflexion from the Caledonian to the Armorican direction. Here, according to De la Bêche, the great coalfield forms three anticlinals which strike to the south-west, but towards the south, these are succeeded by others which strike from east to west. This might well be a case of syntaxis, such as we have already studied in the anticlinals of the foot-

[1] Op. cit., p. 223.

[2] A. Geikie, On the supposed Pre-Cambrian Rocks of St. David's; Quart. Journ. Geol. Soc., 1883, XXXIX, pp. 261-333, map, p. 268;—granite crops out from the overturned limb. On the other hand Hicks, On the Pre-Cambrian Rocks of Pembrokeshire; op. cit., 1884, XL, pp. 507-560, map, where the presence of Archaean rocks is maintained.

[3] J. E. Marr and T. Roberts, The lower Palaeozoic Rocks of the Neighbourhood of Haverfordwest; Quart. Journ. Geol. Soc., 1885, XLI, pp. 476-491, pl. xv.

hills of the Himálaya and of the Hindu Kush on the Jehlam. But there are other tectonic features, particularly in Ireland, which show that we have here, not a case of syntaxis as on the Jehlam, but the encounter of a younger arc with an older folded system, resembling rather the encounter of the Carpathians and the Sudetes in Silesia and north Moravia.

We will not enter in detail into the structure of Hereford and Gloucester, but turn our attention to the south.

7. *The Armorican mountains.* We have seen that in the south of Ireland the Devonian and Carboniferous beds are thrown into great folds, which in the south-west of Cork strike to the west-south-west, but elsewhere, in Cork, Kerry, and Waterford, from east to west, these folds are sometimes overfolded to the north, and they crop out again towards the east in South Wales. We there traced their northern boundary from St. Bride's bay, along the south border of the great coalfields, across Caermarthen bay and Swansea bay to the neighbourhood of Cardiff on the lower Severn. This line is distinguished near Tenby in Caermarthen bay, and in Swansea bay, by overthrust inversion of the Coal-measures; all the country visible to the south of it, namely the three peninsulas on the north side of the Bristol channel, consists, like the folds of Ireland, of anticlinals and synclinals of Old Red sandstone and Carboniferous limestone, in so far as they are not concealed by patches of the transgressive covering of younger sediments which begins here. This transgressive series commences with the Permian and includes more to the east the whole Mesozoic series.

The direction of the northern boundary of the Armorican system and of its folds themselves is here east and a little south, and the continuation of the bands of Carboniferous limestone across the Bristol channel is marked by rocky islands, such as the Steep Holme, for example. This islet was rightly recognized by Buckland and Conybeare, in the year 1824, as the fragment of a fold overturned towards the north. These keen-sighted observers also perceived that the island of Flat Holm, lying a little to the north of the Steep Holme and likewise formed of Carboniferous limestone, is a flat anticlinal striking north-east towards the peninsula of Brean Down; we can therefore no longer assign it to the Armorican folds[1].

[1] W. Buckland and W. D. Conybeare, Observations on the South-west Coal District of England, Trans. Geol. Soc., 1824, 2nd ser., II, pp. 214–232; figure of the inverted stratification on Steep Holme, p. 233. The peculiar manner in which the mountain chains meet, the rectilinear, south-westerly strike in north Wales, and the bend to the south-west which the Silurian zone presents near St. Bride's bay may be seen on Ramsay's general map, Geology of North Wales, Mem. Geol. Surv., 1866, vol. III. A slight deviation in north Wales from a south-west or south-south-westerly direction to one somewhat more southerly is shown in the diagrammatic sketch of the directions of strike given by Larivière, Notes d'un voyage aux ardoisières du Pays de Galles, Ann. des Mines, 1884, 8e sér., VI, pl. xiii, fig. 1.

Thus the Steep Holme, situated north of Bridgwater bay, leads us to the long anticlinal of the Mendips, which extending from the sea-coast towards Frome forms the most northerly of the Armorican anticlinals. It consists of Carboniferous limestone through which the Old Red sandstone makes its appearance in four exposures. In its eastern part the arching passes into overfolding to the north; the Coal-measures lying in front of it on the north are crumpled up in zigzags, and dip towards the south beneath the anticlinal of Carboniferous limestone. The lie of the beds bears so strong a resemblance to that of the Belgian Coal-measures, also overfolded from the south, that, as early as 1824, Buckland and Conybeare, availing themselves of the descriptions given by Omalius d'Halloy, compared the eastern part of the Mendips with the neighbourhood of Namur and Lüttich[1].

Near Frome the Carboniferous disappears beneath the Cretaceous, but the anticlinal of the Mendips is continued, as we shall see, in the form of a much more recent anticlinal towards the east. South of the Mendips, at the head of Bridgwater bay, lies alluvial land with patches of Mesozoic, but soon there rises in the south-west the extensive Devonian region which forms west Somerset, Devonshire and Cornwall.

This great peninsula belongs entirely to the Armorican folds, and the strike of the Devonian and Carboniferous beds, of which it is chiefly formed, corresponds precisely, especially in the northern region, to that of the Mendips. It presents on the north a zone of Devonian rock, which strikes from Bridgwater and the Quantock hills towards Lundy island, the northern half of this island being formed by an intrusion of more recent granite; then follows a broad central zone, in which the Culm beds attain a considerable development, and last a southern Devonian zone, which includes the greater part of the south coast of the peninsula and the southern half of its Atlantic coast. This southern Devonian zone is marked by a series of great post-Carboniferous granite bosses. The most easterly and extensive of these forms Dartmoor forest, south-west of Exeter; a second lies west of Liskeard, a third north of St. Austell, a fourth west of Falmouth; the larger mass which follows forms the extreme end of the peninsula as far as Land's End, and the Scilly isles are the summits of another granite mass covered by the sea[2].

[1] Tom. cit., p. 220; for the Mendips in particular, C. Moore, On Abnormal Conditions of Secondary Deposits when connected with the Somersetshire and South Wales Coal Basin, Quart. Journ. Geol. Soc., 1867, XXIII, pp. 449–568, in particular p. 451 et seq.; H. B. Woodward, Geology of the East Somerset and the Bristol Coalfields, Mem. Geol. Surv. England and Wales, 1876, pp. 22, 190 et seq. Attempts to explain the inversion of the Coal-measures by the method adopted in this work have only led to far greater complications; cf. H. B. Woodward, Remarks upon Inversions of Carboniferous Strata in Somersetshire, Geol. Mag., 1871, VIII, pp. 149–154.

[2] A. Sedgwick and R. I. Murchison, On the Physical Structure of Devonshire; Trans. Geol. Soc. 1840, 2nd ser., V, pp. 633–704, pl. l–lviii, map. The Devonian of north

The granite masses cause considerable local disturbances in the strike, which otherwise faithfully follows the curve of the Armorican folds. From the west of Liskeard down to the Scilly isles the series of granite masses is directed more to the south-west than we should have expected from the strike of the folds in the Bristol channel, and it has therefore been supposed that they are independent of the strike. But the slight deviation to the south-west corresponds to the similar deviation in Cork, e.g. in Bantry bay, and this shows that the vertex of the Armorican arc lies between Ireland and Wales or in Pembrokeshire. Further we shall see soon that the two granite masses of the Harz, which are precisely analogous to those of Cornwall, are by no means disposed according to the strike. De la Bêche conjectured the existence of a subterranean connexion between the granite masses, and with admirable sagacity recognized, as early as 1846, that it was not by their eruption the mountains had been upheaved, but as a consequence of a much more general force which at the same time manifested itself in folding.

South of the series of granite masses, along the south edge of the southern Devonian zone, Archaean rocks crop out on the south coast in two restricted areas at the Lizard in the west and Prawle Point (south of Dartmouth) in the east. These rocks form the foundation of the Devonian mountains, though in the south these also include Silurian deposits. In the first locality, or the Lizard, hornblende schists and serpentine are visible; in the second at Prawle Point, chloritic schists and mica schists. At the Lizard the strike is south-west, corresponding to that of the south-west of Ireland and of the series of granite masses; at Prawle Point it is directed east and west. Between these two places reefs of rock rise from the sea, one of which bears Eddystone lighthouse: these consist of gneiss.

Let us now attempt to obtain a general view of the mountain fragment of south-west England. The most ancient foundation is seen in the south as the gneiss of the Eddystone. This is followed by fragments of an ancient mantle of schists, the hornblende schists of Lizard Point in the west, and the chloritic and mica schists of Prawle Point in the east. Thus we reach the great southern zone of Devonian, with subordinate bands of Silurian, which encloses the long series of granite masses extending from the Scilly isles to Dartmoor; then further to the north follows

Devon, which forms the south coast of the Bristol channel, is formed of beds regularly inclined to the south, which dip beneath the Culm of the synclinal, but immediately in front of the east boundary of the horst they experience, evidently owing to a local advance of the mountains, a sigmoid flexure of the strike towards the north, and in front of this east boundary stand, as a fairly independent fragment, the Quantock hills, in which the elbow is continued. But the return to the normal direction of the Mendips takes place deep below the ground and is invisible. These relations are very clearly shown on the map by Etheridge, Quart. Journ. Geol. Soc., 1867, XXIII, p. 580.

the broad Culm zone, then the north Devonian zone as far as the Bristol channel. At the same time all these mighty deposits are thrown into narrow parallel folds, which are frequently overturned to the north, especially in Somerset. Then still further to the north there follows the anticlinal of the Mendips (beneath which the inverted Coal-measures dip to the south), and the western prolongation of the Mendips, which extends as far as St. Bride's bay.

Such is the structure of a great folded complex, developed under a pressure acting from the south. With perfect justice Bonney remarks that this great series of folds scarcely yields in importance to the existing chain of the Alps, and he compares the gneiss of the Eddystone with the gneiss cores of the Alps[1]. What we see here is the ruins of a mighty mass of lofty mountains; the Lizard and Prawle Point, the last remains of the schist zone, project like cape Matifou and the peninsula of Bonzaréa on the two sides of the bay of Algiers (I, p. 223).

Bonney believes that the foundation of this great mountain region is continued in the ancient rocks of the neighbouring parts of northern France, and to these we will now turn our attention.

The north-west of France is formed of Archaean and Palaeozoic rocks; they form the soil of Brittany and extend from the Cotentin into the Vendée. Towards the east and south their continuation is concealed by Jurassic beds. The eastern boundary of their outcrop runs from the east side of the Cotentin to Alençon, and thence southwards through Angers to Partenay and Saint-Maixent, north-east of Niort. In this region the boundary turns in a right angle to the west, and reaches the sea north of La Rochelle, near Les Sables d'Olonne.

The strike of these older rocks is directed to the west-north-west with deviations to west and north-west, and in the western parts of Brittany the westerly direction appears to predominate. A glance at the excellent but somewhat antiquated map of Élie de Beaumont and Dufrénoy shows us that the peninsula of the Cotentin is a fragment of a great horst, like the Morvan or the Thüringerwald, and that the strike runs transversely across it from east to west, while the lie of the great Armorican peninsula corresponds with the strike.

Much has been written on this part of the country: Dalimier has described the Cotentin; for Normandy I may mention the works of Barrois, Hébert and Lébesconte. It is above all Barrois who has devoted particular attention to the tectonic problems, and, supplementing the earlier investigations of Boblaye, has elucidated the structure of the country[2].

[1] T. G. Bonney, On the Geology of the South Devon Coast from Torcross to Hope Cove; Quart. Journ. Geol. Soc., 1884, XL, pp. 1–25, in particular p. 24.

[2] P. Dalimier, Stratigraphie des terrains primaires dans la presqu'île du Cotentin, 8°, Paris, 1871; C. Barrois, Observations sur la constitution géologique de la Bretagne, Ann.

The whole region, extending through three degrees of latitude, is thrown into nearly parallel folds. Here also the most important folding occurred within the Carboniferous period.

There are two great anticlinals and a number of subordinate ones. The northern of the two great anticlinals forms the peninsula to the north of Brest, with the Montagnes d'Arrée, and extends as far as the Jurassic near Alençon, its northern flank nearly coinciding with the north coast of Brittany; it consists chiefly of Archaean rocks, which are frequently traversed by granite. The southern great anticlinal is formed of Cambrian beds, and is penetrated in many places by granite; it forms the Pointe du Raz, the most southerly of the three spurs which Brittany sends out towards the Ocean, comprises the Morbihan, and runs past Vannes and Nantes. Between these two great anticlinals and to the north and south of them, numerous folds, crowded together, run side by side almost in the same direction; in these also, e.g. near Rostrenen, north of the Morbihan, post-Carboniferous granites have been intruded.

It is a significant fact that the first of the northern synclinals, the Bassin de Mortain, which crosses the Cotentin peninsula north of Alençon, passing through Domfront and Mortain, does not terminate on the coast in the Baie de Cancale, but according to Barrois it reappears more to the west on the north coast of Brittany at cape Frehel, and then, keeping the same direction, runs towards Paimpol and traverses the northern extremity of Brittany.

On the west coast, the northern anticlinal is continued into the island of Ouessant, and the southern passes from Quimper across Pointe du Raz into the little Île de Sein; between these two great anticlinals there lies a broad synclinal, which includes the various members of the Palaeozoic series from the Silurian to the Carboniferous. It embraces many subordinate folds, and extends from Laval on the Mayenne westwards to the sea. To this principal synclinal belongs the irregular-shaped spur which, south of Brest, projects towards the Ocean between its two companions on the north and south.

The whole country is thus folded in the same direction as the south of Ireland and England, and speaking broadly the folding was accom-

Soc. géol. Nord, 1883–1884, XI, pp. 87–91 and 278–285; by the same, La structure stratigraphique des montagnes du Menez, op. cit., 1885, XIII, pp. 65–71; by the same, Aperçu de la structure géologique du Finistère, Bull. Soc. géol. de Fr., 1886, 3e sér., XIV, pp. 655–665, and Aperçu de la constitution géologique de la rade de Brest, tom. cit., pp. 678–706 et passim; E. Hébert, Phyllades de Saint-Lô et conglomérats pourprés dans le Nord-Ouest de la France, tom. cit., pp. 713–774, and Observations sur les groupes sédimentaires les plus anciens du Nord-Ouest de la France, Compt. Rend., 1886, CIII, pp. 230–235, 303–308, and 367–371; P. Lébesconte, Constitution générale du massif breton comparée à celle du Finistère, Bull. Soc. géol. de Fr., 1886, 3e sér., XIV, pp. 776–819 et passim.

plished in both regions at the same time. In breadth this great folded region, now broken up, extends from the Mendips into the Vendée.

In the neighbourhood of Exeter, where the peninsula becomes narrower, the Palaeozoic formations dip beneath a Mesozoic covering, and more to the north, near Frome, the anticlinal of the Mendips disappears in the same manner beneath the more recent sediments. This mantle of younger rocks conceals the foundation of the whole south-east of England. But we have already mentioned that the similarity in the lie of the beds on the north border of the Mendips and in the Belgian coalfield is so great that it was observed many years ago by Buckland and Conybeare. In 1855, Godwin Austen ventured to express the opinion that an actual connexion exists below the ground between the overthrust Coal-measures of the Mendips and those of Boulogne, and that it might even be possible by means of boring to prove the existence of these Coal-measures in the neighbourhood of London itself. He based this view not only on the correspondence in the lie of the beds and the strike of the folds in these two regions, so far distant from each other, but also on the presence of more recent disturbances in the superposed Mesozoic beds, which follow the same strike [1].

The borings which have been made have revealed various Devonian beds at a great depth, and it has been placed beyond doubt that beneath London the Great Oolite rests directly, without any intervening Lias or Trias, upon Palaeozoic beds, as is also the case near Calais, where the continuation of the Belgian forefolding reaches the sea [2]. This forefolding has been discussed in an earlier passage (I, p. 142 et seq.). Along a line running from Boulogne to Aix-la-Chapelle older beds are driven forward over younger. Bertrand compares this zone of forefolding with certain parts of the Alps of Glarus [3]. There is indeed the greatest resemblance to the overfolded outer borders of the Alps, the Carpathians or the Himálaya. That this zone of forefolding finds so little expression in the configuration of the country, and that its presence in the north of France was only discovered by means of borings, has no bearing on the immediate question. All that has been established in this region by mining or by laborious comparative studies finds its sole analogy in the outer borders of the greatest mountain chains now existing, or in that ancient border, exposed by profound abrasion, as the forefolded zone of Eriboll.

A difference presents itself, however, in one striking particular. The

[1] R. Godwin Austen, On the possible extension of the Coal-measures beneath the South-eastern part of England; Quart. Journ. Geol. Soc., 1856, XII, pp. 38-73, map.

[2] Judd, On the Nature and Relations of the Jurassic Deposits which underlie London; op. cit., 1884, XL, p. 754.

[3] M. Bertrand, Rapport de structure des Alpes de Glaris et du bassin houiller du Nord; Bull. Soc. géol. de Fr., 1884, 3e sér., XII, pp. 318–330, pl. xi.

outer borders of the great mountain chains are always more or less convex in the direction of the tangential movement. A concavity or even a re-entrant angle within a region of forefolding has always been regarded as an indication of syntaxis, i. e. of the encounter of two differently directed components of the folding force.

The Belgian zone of forefolding is concave. The descriptions given by Gosselet and Delwaque's map show this plainly [1]. From Calais to Douai the overthrust zone strikes E. 15° S.; between Douai and Valenciennes it is abruptly bent and extremely disturbed; from Valenciennes it turns first east-north-east and then near Aix-la-Chapelle to the north-east. The western part is thus folded from south-south-west to north-north-east; the eastern, on the other hand, from south-south-east to north-north-west and from south-east to north-west, while between Douai and Valenciennes lies the syntaxis in a gentle curve.

Thus *the outer borders of two mountain systems unite in the Belgian zone of forefolding.* The eastern part is the outer border of the Ardennes, and the western is the continuation of the Mendips or the outer border of the Armorican arc. The Armorican arc itself is at this point almost concealed by the overlying Mesozoic sediments. The presence of Palaeozoic beds has, it is true, been established by means of boring in many places west of the coal-bearing zone of Calais-Douai, but it is only near Marquise, north of Boulogne, that the Devonian rises in a small outcrop from beneath the Jurassic mantle. From this place the strike passes across to England.

The folds of the south of Ireland, those on the north side of the Bristol channel, the anticlinal of the Mendips, the folded region of Somerset, Devon, and Cornwall, the ancient folded mass of the Cotentin, Brittany, and the Vendée; then, to the east, the Devonian island of Boulogne and the western half of the forefolded zone of Belgium in its course from Calais to Douai; all these we now see unite together to form the great Armorican arc. A broad gap however remains between Exeter and Boulogne.

The formation of this arc took place towards the close of the Carboniferous period; the great mountains were then worn down by denudation, and covered unconformably by thick deposits of more recent sediments. Then piece by piece the mountains collapsed, and one of the most extensive subsidences is that between Exeter and Boulogne. It appears, however, that within the limits of this subsidence *fresh foldings subsequently occurred which followed the ancient Armorican direction.*

In the region indicated above, between Exeter and Boulogne, lies the

[1] J. Gosselet, Esquisse géologique du Nord de la France, fasc. Terrains primaires, 8°, Lille, 1880, atlas; G. Dewalque, Carte géologique de la Belgique, folio, Brussels, 1879.

denuded dome of the Weald. Bounded on all sides by the escarpment of the Chalk, it rises over an elliptical area, which includes the greater part of Sussex and a part of Kent, and extends some distance beyond Boulogne.

Hopkins showed in 1841 that this dome consists of several parallel anticlinals—three to four, at least—closely crowded together; in the west they strike east to west, but in the east they are deflected to the south-east, in the direction of their prolongation into the Boulonnais [1].

In France it was found by d'Archiac, in 1846, that the watershed of Artois marks an important boundary line in relation to the development of the Cretaceous system, and that this line, which he called the 'axe de l'Artois,' runs to the north-west (W. 34° N.) from Arras, but that in the Boulonnais it undergoes a deflexion to the west, and is continued beyond the Channel into the Weald [2]. The axis of Artois, however, corresponds with the zone of overthrust Coal-measures, which, as we have seen, forms the outer border of the Armorican folds; on its site borings have been made which reached Palaeozoic beds, and the Devonian outcrops in the neighbourhood of Boulogne already stand within the Cretaceous escarpment which extends from England, and bounds the anticlinals of the Weald.

As early, therefore, as 1846 a number of folds were known, having the form of a circular arc, which run first to the west-north-west, then curve across the Channel and extend in a more and more east to west direction through the south of England.

The significance of the axis of Artois for a knowledge of the English folds has been fully recognized by Godwin Austen, and formed one of the most important arguments in support of his theory that the coalfields of Mons and the Boulonnais must find a subterranean continuation beneath the neighbourhood of London and as far as the coal districts north of the Mendips. Indeed, Godwin Austen in his now famous treatise on this subject even maintained as a universal law that when any zone of the earth's crust is considerably folded or fractured, subsequent disturbances

[1] William Hopkins, On the geological Structure of the Wealden District and of the Bas-Boulonnais; Trans. Geol. Soc., 1845, 2nd ser., VII, pp. 1–51, map. The meridional transverse fractures described by Hopkins are partly true flaws, i. e. dislocation planes like the Medina fault in the isle of Wight. The important earthquake of April 22, 1884, would thus be a flaw-shock, like so many Alpine earthquakes, and an indication of the persistence of forces similar to those acting in the Alps; Meldola and White, Nature, January 21, 1886, p. 265.

[2] D'Archiac, Études sur la formation crétacée des versants sud-ouest, nord et nord-ouest du Plateau Central de la France, Mém. Soc. géol. de Fr., 1846, 2e sér., II, p. 116; on the map pl. 1, a dotted line shows the supposed connexion of the axis of Artois with the Weald. At that time the Coal-measures were supposed to be overthrust near Arras; this conjecture was confirmed by borings; Degoussée and Laurent, On the Valenciennes Coal-Basin, Quart. Journ. Geol. Soc., 1856, XII, p. 252, pl. v.

follow the previous lines, and this simply because these lines appear to be lines of least resistance[1].

The anticlinals of the Weald were described later in great detail by Topley, and their deflexion towards the Boulonnais may be regarded as completely established[2].

But these anticlinals are continued towards the west across the region of the Weald; and in addition a new and mighty anticlinal succeeds in the south, which again brings the deposits of the Weald into view, but lies for the greater part beneath the sea. It is visible in the southern half of the isle of Wight; its northern flank with deeply upturned, and in part even inverted, beds runs through the whole breadth of the island from the Needles in the west to Culver cliff in the east, and the rhomb-like form of the island is determined by the course of the rocks which offer the greatest resistance to denudation[3]. From here it continues to the west across Purbeck to Weymouth; and south of Weymouth, on the peninsula of Portland, we meet with Jurassic beds which are steeply upturned.

While the exploration of these folds was being pursued in England, it was discovered in the north of France that a series of similar anticlinals striking to the north-west exists outside the axis of Artois and parallel to it. They have this character in common with the English folds, that the dip of the northern limb of the anticlinals is steep, while that of the southern limb is very gentle. The most important of these is the line of disturbance of the Pays de Bray, which in the midst of the basin of Paris, between Beauvais and Neuchatel, exposes not only the lower members of the Cretaceous but also the upper Jurassic. This remarkable disturbance was first described by Élie de Beaumont and then in great detail by De Lapparent[4]. Hébert and De Mercy have made known to us yet other folds, also striking to the north-west, but of less importance, and Hébert even believed that he could prove the existence of a second system of disturbances running at right angles to the first[5].

[1] Godwin Austen, tom. cit., p. 62. The folds had been already described by P. J. Martin, On the anticlinal Line of the London and Hampshire Basin, Phil. Mag., 1851, 4th ser., II, pp. 41–51, 126, 189, 278, 366, 471; further, op. cit., 1856, 4th ser., XII, pp. 447–452; and 1857, XIII, pp. 33, 109.

[2] William Topley, The Geology of the Weald, Mem. Geol. Surv. England and Wales, 8vo, 1875, maps; in particular, pp. 216 et seq.

[3] Edward Forbes, On the Tertiary Fluvio-Marine Formation of the Isle of Wight; Mem. Geol. Surv. Great Britain, 8vo, 1856, map.

[4] A. de Lapparent, Note sur le soulèvement du Pays de Bray et l'ouverture de la vallée de la Seine; Bull. Soc. géol. de Fr., 1871, 2e sér., XXIX, pp. 231–238, pl. 1; and by the same, Traité de Géologie, 2e éd., 8vo, Paris, 1885, p. 1420.

[5] Hébert, Note sur la craie blanche et la craie marneuse dans le bassin de Paris, Bull. Soc. géol. de Fr., 2e sér.,1863, XX, pp. 605–681; Ondulations de la craie dans le bassin de Paris, op. cit., 1871, 2e sér., XXIX, pp. 446–472, and pp. 583–595; further, op. cit., 1875, 2e sér., III, pp. 512–546, map; by the same, Ondulations de la craie dans le Nord

Finally, C. Barrois, after a careful study of the numerous works of his predecessors and a detailed examination of the folds in England which traverse the Chalk to the west of the Weald, succeeded in obtaining the following results[1]:—

The axis of Artois leaves France somewhat south of the older rocks of the Boulonnais, reaches England at Dungeness, is continued as one of the anticlinals in the northern part of the Weald, and proceeds with an east to west direction through the Chalk past Kingsclere towards Ham, Frome, and the Bristol channel.

A second line, designated by Hébert the axis of La Bresle, strikes to the north-west, reaches the sea near Tréport, and coincides with that great anticlinal of the Weald which Hopkins calls the line of Greenhurst; this strikes past Petersfield and Winchester through the Chalk, past Stockbridge into the valley of Warminster.

The axis of the Pays de Bray, finally, distinguished by the great extent of the dislocation, must probably be regarded as part of that great fold which runs through the isle of Wight to Purbeck.

Each of these folds is steeper towards the north than towards the south; in some of them the folding movement has certainly continued far into the Tertiary period.

These results are far reaching in their significance. Even if it should be shown later that some of the lines in question do not traverse the whole distance as continuous folds, but that contiguous anticlinals running in the same direction replace each other, as in the Jura, yet this will not affect the fact that there exists a system of folds formed under a movement to the north-east and north, which strikes to the north-west in France, curves round in an arc to west-north-west and west in the region of the Channel, and extends with a westerly strike through the south of England to Weymouth and the Mendips. These lines correspond, however, to the downthrown segments of the Armorican arc and join together the projecting horsts. The region was folded, as we have seen, at the close of the Carboniferous period, was covered with younger sediments and subsided; then there occurred in the same place a folding of the younger sediments, and this more recent folding coincides in direction with the older folding which preceded it.

This phenomenon we term *posthumous folding*. It is very likely that in most other mountain systems repeated movements in the same direction

de la France, Ann. Sci. géol., 1876, VII, Art. no. 2, 48 pp., map; N. de Mercey, Note sur la craie dans le Nord de la France, Bull. Soc. géol. de Fr., 1863, 2e sér., XX, pp. 631–644.

[1] C. Barrois, Ondulations de la craie dans le Sud de l'Angleterre, Ann. Soc. géol. Nord, 1875, III, pp. 85–111; and in particular, Recherches sur le terrain crétacé supérieur de l'Angleterre et de l'Irlande, 4to, Lille, 1876, pp. 114–123.

have occurred at very different times; but seldom do we witness so striking an episode as is here presented in the subsidence of a great segment of a mountain arc between successive periods of folding; and in this example we find clearly displayed the extraordinary constancy in the direction of the folding force.

The result then of all the observations we have now brought together is as follows:—The coast of the Atlantic Ocean, from the mouth of the Shannon to some distance beyond the mouth of the Loire, is formed by the breaking-off and subsidence of fragments of a great mountain chain, which was folded towards the north, and acquired the greater part of its elevation towards the close of the Carboniferous period; its vestiges can now only be traced in isolated horsts and in posthumous foldings. The oldest rocks of this chain may be seen in the Vendée, Brittany, and the Cotentin, as well as in the gneiss of the Eddystone, and the ancient exposures of schist on the south coast of the peninsula of Cornwall. The next zone, consisting chiefly of Devonian deposits, and marked in its southern part by numerous granite masses, forms the peninsula of Cornwall and Devon up to the Bristol channel. The outermost zone, overthrust towards the exterior, is for the most part of Carboniferous age, but beneath it the underlying Devonian also crops out. Its northern boundary, which at the same time represents the outer border of the chain, runs across the south of Ireland to St. Bride's bay, continues close to the north coast of the Bristol channel and along the north side of the Mendips as far as Frome, then, indicated by posthumous movements, it follows close to the north flank of the Wealden dome, the North Downs, and with a gradually increasing curvature to the south-east passes between Boulogne and Calais, and is thence continued beyond Douai.

The breadth of the complex, the mighty inversions and imbrications, e. g. in Somerset and Devon as far south as Exeter, the violent overthrusting of the outer border, the great displacement along certain flaws—even when these are posthumous as in the case of the Medina 'fault,' which runs across the isle of Wight—and finally the series of granitic intrusions in Devonshire as well as in Brittany; all combine to show that we have before us the vestiges of a great mountain range. Towards the north this range forms a flat arc. The last parts visible in the west, as in the neighbourhood of Bantry bay and the coasts of Finistère, show that the remains of this range are continued beneath the Ocean in a west-south-westerly direction, and the islands which lie off many of the promontories offer a slight indication of this continuation. The eastern parts lie beneath the basin of Paris, and here too their strike may be recognized in posthumous movements, as in the Pays de Bray.

This is the great pre-Permian range of western Europe. The traces of its interior and presumably most elevated zone lie in Brittany and the

Vendée; for this reason we give these fragments the general name of the *Armorican chain.*

8. *The Variscan mountains.* The rias-coasts of the south of Ireland, of Cornwall and Brittany, form a very typical part of the outlines of Europe; corresponding to them, on the other side of the Atlantic, are the rias-coasts of Newfoundland and Nova Scotia, which also represent the extremities of a great folded range passing beneath the sea. Starting from Ireland, where the contrast between the north and south is so marked, we have now examined the horsts which exhibit folding in a common direction, as far as the syntaxis between Douai and Valenciennes; these combine to form the Armorican arc, the unity of which is shown by the corresponding course of the posthumous folds.

We will now turn aside for a moment from the subject of this chapter, that is the description of the Atlantic coasts, and following the same method as we have just pursued endeavour to obtain a general view of the mountains of Germany, or the greater number of them. This attempt could not be made earlier, because it was first necessary to become familiar with the idea of a horst, and the closely connected conception of extensive subsidences of the surrounding country; and it was also essential to make ourselves acquainted with that peculiar feature—the arcuate course of the trend-lines and their syntaxis—which is repeatedly exhibited by so large a number of folded mountain chains.

This digression will be as brief as the difficulty of the subject permits. The fragments which I propose to consider are:

(*a*) *The Devonian mountains of the Rhine*, namely the collective masses of the Ardennes, the Eifel, the Westerwald and the Sauerland, and next the Hochwald, Hunsrück and Taunus.

(*b*) *The mountains of the Rhine between Bingen and the lake of Constance*, i. e. the Spessart, Odenwald, Hardt, Vosges and Black Forest.

(*c*) *The Harz.*

(*d*) *The mountains of Saxony*, namely the Erzgebirge and Fichtelgebirge, Frankenwald and Thüringerwald.

(*e*) *The Sudetes* together with the Riesengebirge.

Many of these fragments are bounded on all sides by longitudinal fractures or by oblique transverse fractures; a part of the mountains of Saxony and of the Sudetes sinks beneath the north-German plain; the Carpathians approach the Sudetes at right angles to their strike on the east and even appear to be driven over them (I, p. 186).

All these mountain fragments have this feature in common, that they experienced a great and general folding towards the close of the Carboniferous period; then they were covered by thick deposits of more recent sediments and collapsed later, piece by piece, and at divers times; many underwent subsequently a second folding. Thus far, therefore, their

past history resembles in all points that of the Armorican arc. The basal beds of the downthrown fragments are not always of Permian age; in some places they are fragments of the higher subdivisions of the Coal-measures, pinched into the fractured margin. This is the case on the north, as on the south margin of the Harz, at Ilefeld, Grillenberg and Ballenstedt [1], at Stockheim on the western marginal fracture of the Fichtelgebirge [2], and at Rossitz south of Brünn, on the great fault which separates the Sudetes from the Bohemian mass [3]. Elsewhere and over vast regions the Rothliegende is the lowest member of the subsided series.

The northern and eastern parts, namely the Ardennes, the Devonian mountains of the Rhine, the Harz and the northern part of the mountains of Saxony, as well as the eastern and south-eastern part of the Sudetes, are characterized by the great development of the Devonian system, which is of immense thickness and astonishing uniformity; great regions are formed by this system alone, and in Moravia and Silesia it presents essentially the same subdivisions as on the Rhine. The interior parts of the arc consist more or less exclusively of pre-Devonian rocks, as in the mountains of the Rhine near Bingen, the Erzgebirge, and the western part of the Sudetes with the Riesengebirge.

(*a*) *The Devonian mountains of the Rhine.* We are indebted to the united efforts of German, Belgian, and French investigators, and in particular to the achievements of H. von Dechen, for our knowledge of the structure of this vast region, which extends from Frankfort to Düsseldorf and from Mezières nearly into the neighbourhood of Paderborn.

A uniform strike to the north-east predominates in the whole region, which for the greater part is thrown into folds overturned to the north, or imbricated in true flakes with a south-easterly dip. The coalfields of Belgium east of Valenciennes and those on the Ruhr form the outer border.

The overfolded Coal-measures, from the Boulonnais towards Douai, have been recognized as part of the Armorican arc; from the short stretch of country between Douai and Valenciennes which marks the region of syntaxis, the Coal-measures turn to the east-north-east and north-east, and are still affected by overthrusts on a grand scale. Aix stands on an anticlinal between two coal basins, the basin of Eschweiler in the south, and that of Worms in the north; but still further to the north, in Holland, Coal-measures have been reached by borings beneath the plain [4]. Great

[1] C. E. Weiss, Die Steinkohlen-führenden Schichten bei Ballenstedt am nördlichen Harzrande; Jahrb. k. preuss. geol. Landesanst., 1881, pp. 595–603.

[2] C. W. Gümbel, Geognostische Beschreibung des Fichtelgebirges (Geognostische Beschreibung des Königreiches Bayern, III), 8vo, Gotha, 1879, pp. 555–575.

[3] A. Makofsy und A. Rzehak, Die geologischen Verhältnisse der Umgebung von Brünn; Verh. nat. Ver. Brünn, 1884, XXII, p. 82, and geological map.

[4] G. Lambert, Nouveau Bassin houiller découvert dans le Limbourg hollandais, Rapport, Ann. Soc. géol. Belg., 1877, IV, pp. 116–130; Rapport de M. von Dechen, tom.

dislocations here traverse the coal beds, such as the Feldbiss, with its continuation the Münstergewand, which forms the eastern boundary of the basins just mentioned [1].

On the right side of the Rhine, the continuation of the Coal-measures appears to be moved much more towards the north. According to von Dechen the Coal-measures of the Ruhr have been recognized near Duisburg and Ruhrort; those on the left bank near Vluyn, north of Crefeld [2]; we may therefore conjecture that the Coal-measures which cross the valley of the Rhine are either heaved by a flaw, or bent in a sigmoid curve, and this supposition is in complete accordance with the lie of the folds which follow further to the south.

Such sigmoid curvature is not rare in folded ranges; the advance of one part of the range relatively to another, implied by such a curvature, occurs in several places on the outer border of the Alps. The sigmoid curve is often intersected by flaws striking across it, and is thus resolved into a number of small forward displacements. A ladder-like arrangement of the flaw surfaces is then exhibited by the sigmoid. These may be seen on the smallest scale, as in thin slices under the microscope; and on the grandest, as in great mountain masses. Studer's geological map of Switzerland shows how the anticlinal of the Molasse, as it proceeds to the east from Sankt Gallen and Appenzell, begins to undergo on crossing the Rhine a marked deflexion forwards, i.e. to the north-east, and this leads in Vorarlberg and the adjacent part of Bavaria to the edge of the Bavarian Alps which lie much further to the north. In the same way the great Cretaceous limestone mass, which extends from the Toggenburg through the Säntis to the Iller, describes in the same district, within the Flysch zone, a corresponding sigmoid curve. At the same time a part of this mass lies in flakes, and flaw planes, striking to the north, cut through the Säntis (I, p. 116) [3].

The Rhine crosses the folded Coal-measures between Aix and Düsseldorf in the same manner as it crosses the Alps above the lake of Constance, and it is probable that many of the numerous transverse fractures, along which, in the neighbourhood of Aix, von Dechen observed considerable displacements both in the horizontal and vertical direction, play the same part as the flaws of the Säntis. This is the more worthy of remark

cit., pp. 130–132; F. L. Cornet, Notice sur le Bassin houiller Limbourgeois, tom. cit., pp. 133–142.

[1] H. v. Dechen, Geologische und paläontologische Uebersicht der Rheinprovinz und der Provinz Westphalen (Erläuterungen zur geologischen Karte, II), 8vo, Bonn, 1884, pp. 227, 230; also a much earlier work: Ueber den Zusammenhang der Steinkohlenreviere von Aachen und an der Ruhr, Zeitschr. f. Berg-, Hütt.-, Salinenw., 1885, III, pp. 1–8.

[2] Id., Uebersicht der Rheinprovinz, p. 208.

[3] e. g. Mojsisovics, Jahrb. k. k. geol. Reichsanst., 1873, XXIII, p. 174.

because the earthquakes of Herzogenrath, north of Aix, which continued for several years, proceeded, according to Von Lasaulx, from the greatest of these dislocations, the Feldbiss, and must thus be classed with the group of flaw shocks, like so many earthquakes of the Alps [1].

The most ancient rocks of the Ardennes belong to the Silurian. Gosselet distinguishes three Silurian zones, which, however, are not all of equal value, namely, the zone of Brabant, of Condroz, and of the Ardennes proper [2].

That which is known in Belgium as the zone of Brabant is the common foreland of the overthrust region lying in front of both members of the syntaxis; it has been traced by borings beneath the plain, as far as Brussels and Ostend.

Then towards the south follow the overthrust Coal-measures, already frequently mentioned, and the zone of Condroz is that ridge which has been moved from the south-east over the Coal-measures, recalling by this position the anticlinal of the Mendips (I, p. 142, Fig. 17). Folded Devonian accompanies this zone, and to the south it is followed by a broad synclinal of folded Carboniferous limestone, the basin of Dinant. To the south of this broadens out the extensive region of the Ardennes proper, formed chiefly of lower Devonian beds. Their strike is directed, precisely like that of the Coal-measures, to east-north-east and north-east; they are likewise overfolded from the south-east, and out of their midst there rise—not unlike the gneiss cores of the Alps—four masses which form the Cambrian zone of the Ardennes.

All four masses are built up of Cambrian deposits; neither upper nor lower Silurian is known here. There are two large masses, those of Rocroi and Stavelot, the latter called by the Germans the Hohe Venn, and two smaller, those of Serpont and of Givonne.

The mass of Rocroi, that of Serpont, and the Hohe Venn lie in one and the same zone of strike; the smaller mass of Givonne is situated above Sedan, south of the mass of Rocroi. In all the masses, as well as in the surrounding Devonian, the beds dip towards the south, corresponding to the general inversion. The Belgian geologists maintain that the relations with the Devonian are those of genuine unconformability, but the observations of German investigators do not lead to this conclusion, at least not with the same degree of certainty.

The mass of Rocroi lies on the south-west boundary of the Ardennes, and is cut through obliquely by this boundary south of Hirson, so that its outline somewhat resembles an obliquely intersected ellipse. It is continued in any case across the marginal fractures, beneath a part of the Mesozoic

[1] A. von Lasaulx, Das Erdbeben von Herzogenrath am 22. October 1873, 8vo, Bonn, 1874, p. 141 et seq.

[2] Gosselet, Esquisse géologique du Nord de la France, fasc. 1, p. 17 et seq.

sediments of the plain towards the west. Across this mass the Meuse flows, disclosing a beautiful section; Von Lasaulx has described the constant dip towards the south-east, which is exhibited by all the members of this mass, from Mezières on the south, through the Devonian, the Cambrian mass of Rocroi and the Devonian of its northern flank, up to the Carboniferous limestone of the basin of Dinant on the north [1].

The strike of the Coal-measures, directed first to east-north-east then to north-east, is clearly repeated in the alinement of the three masses of Rocroi, Serpont, and the Hohe Venn; in the most distant part of the Hohe Venn, near Düren, east of Aix, the strike passes with equal clearness into north-north-east.

The Hohe Venn begins north-west of Houffalize and proceeds towards Düren. It is broader in its southern part, and is produced with a slight curvature first to the north-east and then more and more to the north-north-east. This is no doubt the same sigmoid as that described by the strike of the Coal-measures as they cross the valley of the Rhine. The mass of the Hohe Venn is related in the same way to the Coal-measures as the limestone mass of the Säntis and its continuation to the overthrusting of the Molasse. The whole northern part of the anticlinal of the Hohe Venn also shows inverted bedding, and the full force of the sigmoid curvature finds expression on the western side of the extreme end of the mass. In this region near Mérode, as Holzapfel has shown, the lowest member of the south-east side, the lower Devonian, is completely driven over the western limb of the arch, and overlies the upper Devonian and Carboniferous; and immediately to the south of this locality several parallel flaws, accompanied by as many successive forward thrusts, intersect the western limb [2].

[1] A. von Lasaulx, Ueber die Tektonik und die Eruptivgesteine der französischen Ardennen, Vortrag in der Herbst-Versammlung des naturhistorischen Vereines der preussischen Rheinlande und Westphalen, 7. October 1883, 8vo, Bonn, 1884. Gosselet's 'Faille de Remagne' on the south-east side of the little mass of Givonne is a thrust-plane. By the same, Sur la faille de Remagne et sur le métamorphisme qu'elle a produit, Ann. Soc. géol. Nord, 1883–1884, XI, pp. 176–190. I have not considered it necessary to enter in detail into the disputed question whether an original unconformability exists or not between the overthrust Cambrian anticlinals and the lower Devonian, since the imbricated structure is universally acknowledged. Nor have I discussed the question of the existence of traces of a granitic intrusion beneath the Hohe Venn; A. von Lasaulx, Der Granit unter dem Cambrium des Hohen Venn, Verh. naturhist. Ver. preuss. Rheinl., 1884, XLI, pp. 418–450; Dewalque, Sur les Filons granitiques et les Poudingues de Lammersdorf, Ann. Soc. géol. Belg., 1885, XII, pp. 158–163.

[2] E. Holzapfel, Die Lagerungsverhältnisse des Devon zwischen Roer- und Vichtthal, Verh. naturhist. Ver. preuss. Rheinl., 1883, XL, pp. 397–420, map; G. Dewalque, Sur la terminaison N.-E. du massif cambrien de Stavelot, Ann. Soc. géol. Belg., 1884, XI, Bull., pp. cxx–cxxv. In this respect my opinion differs essentially from that of Lossen, a distinguished observer of such phenomena. Lossen sees in this bend of the Hohe

The foregoing will suffice to show to what extent the structure of the northern border of the Rhenish mountains resembles the northern border of the Alps, and I shall now enter less into detail.

The Cambrian masses of the Ardennes, the extremity of which we have just studied near Düren, are not continued across the Rhine. Many series of overthrust anticlinals and synclinals composed of Devonian deposits form the mountains far and wide. Their strike is constantly directed to the north-east, and is clearly expressed in the nosing out of the folds along the eastern border of the Sauerland, the Westerwald and the Taunus, as well as in the general outlines of these mountain fragments. Still, towards the south, the overthrusting appears to be of trifling extent. Synclinal limbs dipping to the north-west, that is, normally inclined, alternate more frequently with opposed limbs dipping to the south-east. On the southernmost edge, from Homburg von der Höhe through Wiesbaden up to the valley of the Nahe, Von Dechen marks a zone of more ancient sericite schists and gneisses as the foundation of the folded Devonian mountains. Their position is similar to that of the ancient schists of the Lizard and Prawle Point, on the inner side of the Devonian formations of Cornwall. According to C. Koch, it is along the axis of a symmetrical anticlinal, close to the most southerly edge of the Taunus, that the sericite gneiss crops out. It is succeeded on each side by green sericite schists, and these again by the phyllite of the Taunus with beds of quartzite. The anticlinal runs to the south-west, crossing the Rhine near Assmanshausen. Only its upper members are visible here; they have closed over the gneiss, and further to the south-west on the left side of the Rhine these too become concealed beneath the now continuous beds of the Taunus quartzite, which in their turn disappear, still further on, beneath the shales of the Hunsrück[1].

Venn, as well as in that of the basins of the Eifel situated further to the south, a torsion or deformation of the anticlinal which originally followed the direction of the Netherlands, by later Hercynian folding. In that case it seems to me there would not be produced a curvature of the existing anticlinals, but the formation of new anticlinals transverse to the original folds. I may add that the radial system of dykes of Andreasberg represented here by Lossen (fig. 12, 1, p. 163), so closely resembles the effect of torsion that I too should be inclined to regard this explanation as the most suitable for the present; on the other hand, I cannot recognize from the data hitherto published any turning round of the whole folded system of the Harz; K. A. Lossen, Ueber das Auftreten metamorphischer Gesteine in den alten paläozoischen Gebirgskernen von den Ardennen bis zum Altvatergebirge, und über den Zusammenhang dieses Auftretens mit der Faltenverbiegung (Torsion), Jahrb. k. preuss. geol. Landesanst., 1884, pp. 56–112. A. v. Groddeck sees in the Harz only folding in the direction of the Netherlands, and this view appears to me to correspond with the observations so far published; op. cit., 1883, p. 73, note.

[1] C. Koch, Ueber die Gliederung der rheinischen Unterdevon-Schichten zwischen Taunus und Westerwald; Jahrb. k. preuss. geol. Landesanst., 1880, p. 198 et seq., section on pl. vi.

(*b*) *The mountains of the Rhine above Bingen.* The southern border of the folded Devonian region is immediately succeeded by the coalfields of the Saar, which present a fundamentally different structure; the nature of the underlying rocks is not known; on the Coal-measures the Roth-liegende lies conformably and without any clearly defined limit. Gentle folds occur and are traversed by numerous fractures. Von Dechen has enumerated many of these in order to show how extreme is the fragmentation of the earth's crust in this region [1]. A mighty fault bounds the Coal-measures on the south; according to Kliver's estimate its throw near Bexbad and Sankt Ingbert amounts to 4,000 meters, near Dudweiler to 3,000 meters. In the south it runs from Saarbrück for some distance past Forbach in the direction of Saint-Avold towards France, probably with a bend to the west-south-west, and Lepsius has followed it to the north-east as far as Alzey in the Rhine valley [2].

Thus this transgressive segment is sharply separated from the more southerly heights by a tremendous subsidence which has taken place along faults following in the main the strike of the Devonian chain, but we must not forget that these mighty movements are much more recent than the folds, the connexion of which we are seeking to trace. The downthrown fragment is also gently folded, either by compression during subsidence or by posthumous movement. It presents a distant resemblance to the great trough subsidence of Edinburgh and Glasgow.

In the north-east the case is certainly different. On the west side of the Spessart, east of Hanau and Aschaffenburg, gneiss and crystalline schists crop out; the northern outliers of the Odenwald near Darmstadt also approach to within 30 kilometers of the southern edge of the Taunus, and are only separated from it by the recent deposits of the Rhine valley. The Odenwald is followed across the Rhine by the exposures of older rocks on the east side of the Haardtwald, emerging, as along the Odenwald and the Spessart, from beneath a thick covering of Bunter sandstone, while still further to the south rise the great horsts of the Vosges and the Black Forest.

We have already described the way in which these mountains have collapsed (I, pp. 194–197) and the Mesozoic table-lands around them have been let down, leaving the existing heights as the ruins of a once continuous range. These fragments have been left standing, like the remains of an ancient edifice surrounded by the ruins of mighty ramparts; and we have now to consider not the circumvallate ramparts but the structure

[1] H. von Dechen, Uebersicht der Rheinprovinz, pp. 269–275.

[2] Op. cit., p. 261; on the closely but not exactly corresponding course of a much later fault, instructive information is given by G. Mayer, Ueber die Lagerungsverhältnisse am Südrande des Saarbrückner Steinkohlengebietes, Mittheil. Commiss. f. geol. Landes-Unters. v. Elsass-Lothr., 1886, I.

of the ancient edifice itself as preserved in the surviving fragments; we must seek to discover the position of the corner-stones, or perchance of some remnant of a still recognizable cornice, so that we may recover the original outline from the ruins. It would thus be our task to examine the direction of the strike and the succession of the rocks in each of these several horsts, were it not that this work has already been admirably accomplished by Richard Lepsius, who has made use of all the observations collected since the time of Peter Merian; it is only necessary, therefore, to recapitulate the results already obtained [1].

All the primitive formations on both sides of the Rhine, from the Jura mountains to the Taunus, have a common strike, and this is parallel to the strike of the Taunus. The whole of this fundamental mass, now broken into fragments, was once folded by a common tangential force acting from south-south-east to north-north-west. Gneiss, mica schists, and isolated beds of Devonian and Culm follow the common strike, which may be disturbed by intrusive granite masses, but only locally or within narrow limits. The folding took place towards the end of the Carboniferous period. On the folded chain, beds 1,200 to 1,500 meters in thickness, ranging from the upper Rothliegende to the upper Jurassic, were deposited; then the chain collapsed along great lines of fracture; and the table-land of Trias and Jurassic rocks subsided at least 2,500 meters during the interval between the Tertiary period and the present day.

From the southern end of the Black Forest and the Vosges, as far as the overthrust Coal-measures near Aix and on the Ruhr, we thus see one and the same system of folds which were formed towards the close of the Carboniferous period. The Black Forest and the Vosges, as far as the ancient rocks of the Spessart near Hanau and Aschaffenburg, stand in the same relation to the Devonian formations of the Rhine, from the Taunus to the Ruhr, as that in which the ancient rocks of Brittany and the Cotentin, together with the gneiss reefs of the Eddystone, stand to the folds of Devonshire and the overfolded Coal-measures on the north side of the Mendips and the Bristol Channel.

Now for the first time we embrace in one view the whole breadth of that great German arc, the outer border of which enters into syntaxis, in the north-east of France, with the outer border of the Armorican arc. It is not inferior in magnitude to the latter, nor are its folds less powerful.

(*c*) *The Harz.* This horst presents the form of an ellipse elongated from west-north-west to east-south-east, but the strike of the beds is transverse, running to east-north-east or north-east. This is very clearly

[1] R. Lepsius, Die oberrheinische Tiefebene und ihre Randgebirge; Forschungen zur deutschen Landes- und Volkskunde, issued by R. Lehmann, I, Heft 2, 8vo, Stuttgart, 1885, p. 52 et seq.

shown in Lossen's beautiful map of the Harz mountains, as well as in numerous detailed descriptions of the district. Lossen believes that this dominant strike has been disturbed in certain localities by later folding in another direction, but Von Groddeck does not regard this as definitely proved [1].

Devonian beds form the greater part of the Harz, and these correspond so closely with those of the Schiefergebirge of the Rhine that Von Koenen regards a subterranean connexion of the two masses as indisputable [2].

Two granite masses, the Brocken and the Romberg, rise out of the Devonian area; they do not extend along the strike of the stratified rocks, but with this exception resemble in their most important features the granite bosses in the Devonian region of Cornwall. They produce at most only a local deflexion of the general strike. The whole of the upper Harz is folded, according to Von Groddeck, into an anticlinal, both limbs of which are thrown into subsidiary synclinals and anticlinals. The south-east limb is vertical or overturned, while the north-west limb has a regular and gentle dip [3]. In the central Harz, Kayser describes a great anticlinal of lower Devonian, which strikes from Herzberg and Lauterberg on the south-west border of the mountains to east-north-east or north-east, straight across them to Ramberg; it is followed both on the north and south by many parallel folds [4]. Towards the north, in particular on the south-west side of the Brocken, folds occur striking directly on to the granite mass; they are preserved as altered fragments resting on the back of this laccolite, which is now exposed by erosion. Most of these folds are overthrust to the north-west. In the south-east part of the Harz the same strike prevails, but the overthrusting to the north-west does not occur here. On the contrary, it appears from Lossen's description that towards the south-east border overfolding of the beds takes place in the opposite direction, so that in this part of the Harz fan-structure is met with [5]. In the Schiefergebirge of the Rhine also, the overfolding to the north-west diminishes as we approach their south-east border. The Harz, indeed, is merely a portion of the Rhenish Schiefergebirge.

(*d*) *The mountains of Saxony.* The east-north-east to north-east strike of the Black Forest points to the middle of the great fractured area of south Germany. The country to the north of Tübingen and Nürnberg

[1] A. von Groddeck, Jahrb. k. preuss. geol. Landesanst., 1883, p. 73, note; cf. above, note 2 on p. 101.

[2] e. g. A. von Koenen, Ueber Dislokationen westlich und südwestlich vom Harz; op. cit., p. 45, 1884.

[3] A. von Groddeck, Zur Kenntniss des Oberharzer Culm; op. cit., 1882, p. 67.

[4] E. Kayser, Ueber das Spaltensystem am südwestlichen Abfalle des Brockenmassivs, insbesondere der Gegend von Sankt Andreasberg; op. cit., 1882, p. 424.

[5] (Lossen); Erläuterungen zur geologischen Specialkarte von Preussen und der Thüringischen Staaten; Gradabth. 56, Nr. 30, Blatt Wippra, 1883, p. 36.

must have for the base of its foundation the continuation of the Black Forest, and as soon as we pass Baireuth and cross the marginal fractures on the east of the great subsidence the older rocks reappear with the strike of the Black Forest.

The chief ridge of the Erzgebirge continues the north-easterly direction as far as the Elbe. On the Bohemian side this is cut off by a great fracture, on which a long series of Tertiary volcanos once rose. Towards Saxony and Thüringia, however, there follows a series of great parallel folds driven towards the north-west, which form all the country for a great distance into the plain.

We will first consider the Fichtelgebirge and the Frankenwald. The structure of this region is determined by two directions; one, the more important, is to the north-east, the other to the north-west. Gümbel, however, has justly pointed out that the first or generally dominant direction finds expression in folds, the second in fractures; but it is the folds only which now interest us, and not the fractures, which are of much more recent date[1]. From Gümbel's very detailed descriptions it further appears that the great granitic intrusions of the Fichtelgebirge and Selb, which surround the sources of the river Eger, influence the general strike of the gneiss and the ancient schists on the north-east to so small an extent that even the Cambrian fragment of Wunsiedel, surrounded on three sides by granite, retains the normal strike unchanged. Thus the Fichtelgebirge is but the western extremity of the Erzgebirge, and the same strike is maintained from the marginal fractures of the south-German subsidence, near Goldkronach, as far as the Elbe. The Erzgebirge, however, is the principal and characteristic range of the whole mass of Saxony.

Towards the north this principal range is immediately followed on the west by closely folded Palaeozoic slates, and then rising out of them comes the gneiss of the Münchberg in a broad elliptical mass. It extends to the north-east from the marginal fractures into the immediate neighbourhood of the town of Hof, where the Cambrian appears and forms its border. The Münchberg mass presents a most instructive picture of a gneiss core of the Alps, denuded almost to its base. The smaller folds and crumplings have vanished; the simplified elliptical outline and the overfolding to the north-west remain[2].

The strike to the north-east is maintained throughout the whole of the Frankenwald and also through the Thüringerwald, so far as it is not concealed by Permian rocks. We know that the Thüringerwald is a horst, bounded on one side by the continuation of the marginal fractures of the

[1] C. W. Gümbel, Geognostische Beschreibung des Fichtelgebirges mit dem Frankenwalde und dem westlichen Vorlande (Geognostische Beschreibung des Königreiches Bayern, III), 8vo, Gotha, 1879, in particular pp. 97, 628 et seq.

[2] Id., op. cit., p. 635 et passim.

great south-German sunken area, which extends past Coburg and Meiningen, and on the other side by the marginal fractures of the northern sunken area in the neighbourhood of Gotha and Weimar. Thus, then, in the Thüringerwald, the beds strike transversely across the mass, and this range of heights reproduces the structure of the Cotentin [1]. The strike of the beds in eastern Thüringia, the Carboniferous age of the chief folding, and the Permian transgression have been described in detail by Liebe [2].

Refraining from all detailed description we now pass to the structure of the western part of the kingdom of Saxony. This is another fragment of the same mass.

In 1876 H. Credner expressed for the first time the opinion that the Erzgebirge is not an independent mountain range, but rather the most southerly of three parallel folds which run from south-west to north-east through the west of Saxony. The middle fold to the north of it is a very symmetrical anticlinal, known as the Mittelgebirge or the granulite mountains of Saxony, and the most northerly fold, also an anticlinal, though covered for the greater part by recent alluvial land, forms the mountains of Liebschütz, near Strehla on the Elbe [3].

Just as the elliptical mass of the Münchberg gneiss lies in front of the western Erzgebirge, so here, in front of the same chain, lies the ellipse of the Saxon Mittelgebirge, directly north of Chemnitz. The towns of Glauchau, Rochlitz, Döbeln, and Hainichen may serve to indicate its boundary. The ellipse is somewhat larger than that of the Münchberg, its border more regular and its abrasion still further advanced, but the main features of its structure are the same, and Credner's map of the range, like Gümbel's map of the Münchberg mass, gives us the plan of a much worn-down mountain core [4].

[1] The north-easterly strike of the Thüringerwald is clearly represented on Richter's general map in Zeitschr. deutsch. geol. Ges., 1851, XX, pl. xx; likewise in Credner, Versuch einer Bildungsgeschichte des Thüringerwaldes, 8vo, 1855, and in more recent works, e. g. H. Loretz, Beitrag zur geologischen Kenntniss der cambrisch-phyllitischen Schieferreihe in Thüringen, Jahrb. k. preuss. geol. Landesanst., 1881, p. 244, in particular the corresponding sheet of the special map; in the present work the fractures have been discussed in vol. I, p. 193. Lately Loretz has distinguished in the south-east of the Thüringerwald, besides the close and general folding in the direction of the Erzgebirge, other wide undulations, on a great or even very great scale, most of which also strike to the north-east but some to the north-west; Loretz, Zeitschr. deutsch. geol. Ges., 1886, XXXVIII, pp. 468, 469.

[2] K. T. Liebe, Uebersicht über den Schichtenaufbau Ostthüringens; Abh. geol. Specialkarte, Preuss. etc., 1884, V, pp. 398 and 530, map, et passim.

[3] H. Credner, Das vogtländisch-erzgebirgische Erdbeben vom 23. November 1875, Zeitschr. ges. Nat. Halle, 1876, XLVIII, p. 261; also by the same, Ueber das erzgebirgische Faltensystem, Vortrag gehalten auf dem 2ten deutschen Bergmannstage, 8vo, Dresden, 1883.

[4] Id., Das sächsische Granulitgebirge und seine Umgebung, 8vo, Leipzig, 1884, map, in particular p. 61 et seq.

A noteworthy interval lies between this great ellipse and the Erzgebirge. The Archaean rocks of the Erzgebirge are followed by a Silurian zone; then to the east of Hainichen and Frankenberg the gneiss of the Erzgebirge appears once more, as a wedge 20 kilometers in length, and between this and the border of the ellipse lie Culm and Cambrian phyllite. To the south-west, however, in the direction of Chemnitz the steeply upturned Culm is covered by upper Carboniferous of the same age as Saarbrück beds, and by Rothliegende. These younger beds are horizontal, and indicate once more, as in so many other places, the magnitude of the disturbances which must have occurred before the conclusion of the Carboniferous period.

It is the most northerly of the three anticlinals of Saxony which lies most deeply buried beneath younger deposits. Its oldest rocks crop out, as we have seen, near Strehla. Credner has shown that the series of exposures of greywacke, which begins at Hainichen and Otterwisch (north-east of Borna), runs over the Deditzberg near Grimma to the Collmberge and nearly up to the Elbe, corresponds to the southern side of the anticlinal, while the northern flank is visible immediately to the south of Leipzig [1].

This anticlinal reaches the Elbe with an east-north-east strike, but near Riesa, not far to the south-east of it, there crop out Archaean rocks, which strike from north-west to south-east in the direction of the Riesengebirge and the western part of the Sudetes. In these exposures of Riesa we may doubtless recognize the continuation of the long gneiss band of Grossenhain, which, according to Naumann, proceeds from the district north of Dresden, and runs from the south-east in a gentle curve to reach the Elbe directly east of Riesa. A broad tract of Palaeozoic rocks extends north of this band of gneiss into the neighbourhood of Ortrand, and forms the commencement of the great Palaeozoic zone which runs from this point through the whole of Lusatia to lower Silesia, past Königsberg, Camenz, and Görlitz, to the graptolite slates of Lauban; it forms an important element in the structure of the Sudetes, and may be

[1] H. Credner, Der Boden der Stadt Leipzig, 8vo, Leipzig, 1853, p. 7. Professor Credner has been kind enough to furnish me with the following observations which have an important bearing on the questions treated here: (1) Phyllites of Wellerswalde, strike N. 75° E., dip steep to SSE.; (2) Andalusite mica schists of Clauschwitz, strike N. 60° E., dip vertical; (3) numerous outcrops of lower Silurian greywackes, strike N. 45°–50° E. to N. 60° E., sometimes N. 70° E., dip steep to south. The greywacke presents in its eastern course towards the Elbe a strike of N. 45°–50° E., further to the west towards the Collmberge of N. 60°–75° E. As far as Hainichen, strike WSW.–ESE. and dip to the south. SSE. from the Strehla mountains and S. of Riesa some isolated bosses of crystalline schists (gneiss, hornblende schist, &c.) emerge from the diluvium. These strike SE.–NW., that is almost at right angles to the greywacke zone of Oschatz-Strehla. The detailed survey of Lusatia is not yet completed.

followed much further still, striking at first east-south-east, then south-east, and afterwards more and more to south-south-east.

Notwithstanding the deflexion of the strike at what is supposed to be the north-eastern extremity of the gneiss band of Grossenhain (a deflexion compensated further to the east by a great extension of the greywacke zone), I nevertheless believe that the greywacke exposed on the left bank of the Elbe up to Oschatz and Strehla must be regarded as a continuation of the greywacke on its right bank. In this I agree with Naumann and Cotta, who assumed the existence of such a continuity many years ago [1].

(*e*) *The Sudetes.* A tremendous fracture cuts off the south side of the Riesengebirge and extends beyond Dresden. On the outer edge of the mountains, as we have already seen, the folded zones on the two sides of the Elbe fit together fairly well. The eastern, that is the Sudetic side of the mountains, shows this adaptation to a common arc most plainly, for towards Moravia the strike becomes almost north-east. From this point the several zones of the mountains must bend round through 90° in order to adapt themselves in some measure to the arc, and this they do.

I do not propose to discuss in detail the structure of the Sudetic arc, since the authors of the geological maps of lower and upper Silesia have represented it in so clear a manner. The arcuate plan would be still more obvious were it not, apart from the fracture of the inner border, that there is a complete absence of correspondence between the outer border of the mountains and their structure. From the Katzbach onwards, past Freiburg and Jauernig the mountains are cut off obliquely by a long line, which cannot be other than a fracture, and beyond Jauernig on the one hand and Ziegenhals and Hotzenplotz on the other we see the several Palaeozoic zones of the arc with a north-north-west strike disappear one after the other beneath the plain. Their continuation probably lies concealed somewhere to the north of the Zobten.

The stratified series of these mountains, particularly the Devonian, shows, as we have already seen, a close resemblance to that of the other fragments of arcs as far as the Rhine. In this region also the most important movements occurred towards the close of the Carboniferous period, certainly before the Rothliegende. The subsequent folding, not only of the Permian but also of the transgressive Cretaceous beds, into synclinals which follow the general strike of the arc, as on the Heuscheuer and in the basins of Löwenberg and Lähn, shows that posthumous movements have occurred similar to those of the south of England.

[1] B. Cotta, Erläuterungen zu Section VI der geognostischen Charte des Königreiches Sachsen, 8vo, 1839, p. 46; Naumann und Cotta, Erläuterungen zu Section X, 1845, p. 448.

Great masses of granitic rocks rise out of the western part of the chain on its inner side; but Roth very justly remarks that the foldings and dislocations of the stratified rocks cannot be ascribed to the granite; these phenomena are more probably connected with movements of the earth's crust 'during which opportunity was afforded to the granites to force their way upwards.' Beyrich thinks we may assume that these granites, like those of the Harz and Devonshire, were intruded during the Devonian or the early part of the Carboniferous period [1].

In lower Silesia the chief structural features of the country have been determined by F. Roemer, and the researches carried out on Austrian territory show that in the neighbourhood of the Altvatergebirge phenomena of compression occur which equal in intensity those of the Alps, both as regards the position of the strata and the alteration of the rocks [2].

(*f*) *Summary.* We have now reached the eastern extremity of the great shattered mountain arc of Central Europe. Its outer border may be traced from the syntaxis near Valenciennes as far as the Rhine, and after it has crossed the river in a sigmoid curve may be followed some distance further along the Ruhr; its continuation on the east lies in the coalfields of lower Silesia and Moravia. Towards the interior follows a broad zone, chiefly Devonian, which extends through the Ardennes, on the Rhine up to the southern border of the Taunus, in the Harz, and in the more distant parts of the Sudetes. The zones lying still further towards the interior consist principally of crystalline rocks; they are traversed by more closely folded zones of Silurian, Devonian, and Culm, and form the mountains of the Rhine from the Taunus up to the southern end of the Black Forest, the Fichtelgebirge and Erzgebirge with the Frankenwald and Thüringerwald, the Riesengebirge, and a part of the Sudetes.

Like the Armorican mountains this arc was folded chiefly towards the close of the Carboniferous period, certainly before the Rothliegende, and was broken up at various times. But here too posthumous movements have occurred, and these appear most clearly in the Cretaceous basins of the Sudetes. Great transgressions over the folds begin in the upper Carboniferous, as for example in the coal district of the Saar.

The highest summits of this ancient range probably stood on the site of the Ballons des Vosges, in the south part of the Black Forest, on the line running thence to the Erzgebirge, on this range itself, and on the inner side of the Sudetic fragment. But nowhere do the outlines of the ancient

[1] Justus Roth, Erläuterungen zu der geognostischen Karte vom Niederschlesischen Gebirge und den umliegenden Gegenden, 8vo, Berlin, 1867, p. 390.

[2] A new series of researches is now in progress; von Camerlander, Reisebericht aus W. Schlesien, Verh. k. k. geol. Reichsanst., 1886, pp. 294–301; F. Becke and M. Schuster, op. cit., 1887, pp. 109–119.

mountain cores stand out so clearly as in front of this main line, in the gneiss mass of the Münchberg near Hof, and in the granulite mountains of Saxony. It is thus fitting that the name of this range, which includes most of the German horsts, should be borrowed from the land of the Varisci or the Vogtland; and we shall name it therefore the *Variscan range*, from the Latin name of Hof in Bavaria (*Curia Variscorum*).

9. *The syntaxis of Central Europe.* In a previous chapter (I, p. 421) we became acquainted with the syntaxes of India. The arcs of the Himálaya and those of the Hindu Kush advance like a succession of gigantic folds on the surface of two viscous streams moving to the south-west and south-east; they meet each other along a line, indicated in the south by the river Jehlam, which may be followed far into the mountain region with a direction almost due north, only deviating a little to the east. We see, besides, that the folds of the forelying Tertiary land follow similar lines, though the re-entrant angle of the outer border is somewhat more obtuse than at the junction on the inner side of the chains.

We must now turn our attention to the syntaxis of the Armorican with the Variscan folds. In the great mountain-ranges of Asia the chief obstacle to a more exact knowledge of the country lies in its impracticable nature; here the difficulties are of another kind. Everywhere the chain is completely worn down, so that scarcely a trace of the original configuration of the surface can be recognized; on the ground plan thus lying before us, the true lines of structure, appearing generally as long denuded folds, or parallel fractures of great length, must be carefully distinguished from a number of others, various in character and of secondary importance, or from merely superficial features, frequently regarded as characteristic. In determining the orientation of the so-called mountain systems we depend sometimes on the direction of intrusive granite cores or lines of volcanos, sometimes on the marginal fractures of horsts, and often even on the trend of ridges formed by erosion, or indeed of watersheds. But it is evident that in folded ranges only the folds themselves and the longitudinal fractures or thrusts, by which they are accompanied, should be taken into account, and it is equally evident that in a profoundly abraded range Archaean rocks will form the greater part of the surface; of the sedimentary beds which once covered them, only the innermost wedge-shaped extremities of the chief synclinals will be preserved.

From this it follows that the very long pinched-in bands of Silurian, Devonian, Culm, and Carboniferous, which may be met with here and there in the Archaean regions, furnish the true trend-lines and guide us to the course of the great mountain ranges of former times.

In the region where we might expect to find the inner branches of the two ancient mountain arcs of Central Europe uniting in syntaxis, rises the Central Plateau of France. This vast mass, composed chiefly of gneiss and

granite, terminates in the east, towards the valley of the Rhone and the Saone, in a long slope running north and south, which, as we shall see directly, cuts obliquely across the structural features of the mass, and is therefore a fracture. From the neighbourhood of Valence and Privas, where a great stream of basalt flows down from the heights into the valley, the boundary line of the Central Plateau trends to the south-south-west, nearly as far as Le Vigan on the upper Hérault, and even further, to Carcassone, if we include the Montagne Noire; thence it runs to the north-west, describes a concave arc in the direction of Figéac, passes to the east of Périgueux, turns round Limoges in a broad curve and then runs east-north-east past Saint-Amand towards Avallon at the northern point of the Morvan.

This outline is interrupted by three great bays. Two of them lie close together and correspond to the valleys of the Loire and the Allier; one of these cuts off the Morvan; they are separated from one another by the spur-shaped range of Forez. We have already seen that the Morvan, which projects towards the north, is surrounded by faults (I, p. 204); it may be compared to the Cotentin and the Thüringerwald. The two river valleys right and left of the chain of Forez are filled with fresh-water deposits of the upper Tertiary, and, on the Allier especially, with the products of recent volcanos.

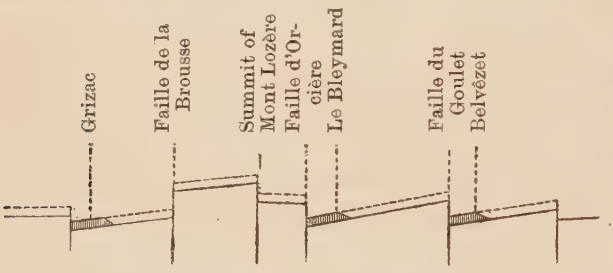


FIG. 11. *Diagrammatic section of the Archaean foundation and fragments of Mesozoic rocks on Mont Lozère*, after Fabre [1].

The southern 'bay' differs completely in structure. It opens north-west of Montpellier between Le Vigan and Lodève and extends with an irregular outline to the north-east as far as Mende, to the north-west into the region between Lot and Aveyron. This region, surrounded by mountains of gneiss and granite, consists of Jurassic limestone forming plateaux which for the greater part bear the name of 'les Causses.' The plateau of Larzac forms its southern part. The whole region of the Causses is generally regarded as a 'Jurassic gulf,' and the Cevennes and the Montagne Noire as the shores of this gulf [2]. Against this conception, however, the steep and bare escarpments of the Causses, as well as the

[1] P. Gourret, Constitution géologique du Larzac et des Causses méridionaux du Languedoc; Ann. Sci. géol., 1884, XVI, pp. 1–229, map and plate.

[2] G. Fabre, Sur les preuves de la submersion du Mont Lozère à l'époque jurassiqué; Bull. Soc. géol. de Fr., 1873, 3e sér., I, p. 323.

numerous faults by which they are traversed, suggest a warning. The Causses are only a downthrown fragment of the vast Mesozoic covering which once extended over a great part of the Central Plateau and here remains preserved. The same explanation applies to the survival of a patch of Keuper, on the summit of the Souquet in the Cevennes, at a height of 1,300 meters[1].

While the Central Plateau is thus bounded on the north-east, east, and south by lines of fracture, its extreme western end is seen to dip beneath the depression of Poitiers; and since the Archaean foundation is visible in so many places between this western end and the south-eastern part of the Archaean hills of the Vendée and Deux-Sèvres near Saint-Maixent, which lies opposite to it, it is clear that the superficial covering which separates the Central Plateau from the mass of Brittany is of very trifling thickness.

Volcanic masses, such as the Mezen and the eruptive centres between

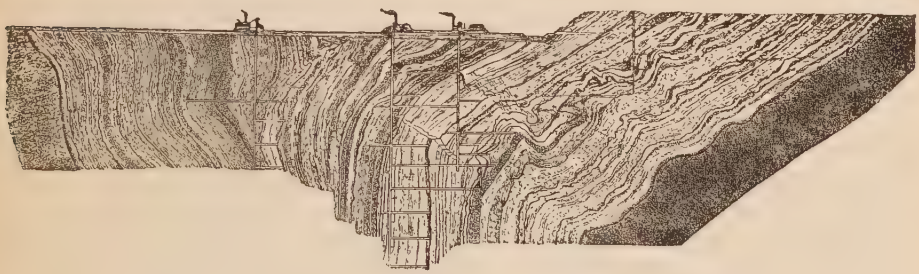


FIG. 12. *Section through the Anthracite basin of* Chalonnes *on the lower Loire,* after Fagès[2].

the Loire and the Allier, the Cantal, Mont Dore and the volcanos near Clermont, are superposed on the Central Plateau, but they do not concern us here, since our object is to determine the direction of the syntactic folds.

Let us begin our description in the west.

An extremely thick band of gneiss and granite runs from the Morbihan in a south-easterly direction past Nantes to Partenay and Saint-Maixent. It is clearly the same as that which becomes visible below Poitiers and is continued into the Central Plateau. On its northern edge we observe a continuous band of Devonian and anthracite-bearing Culm beds, over 100 kilometers in length, which is pinched into the ancient formations. It begins near Nort, north of Nantes, describes like the Armorican arc a gentle curve to the north, is cut through obliquely by the Loire near Chalonnes,

[1] E. Dumas, Statistique géologique, minéralogique, métallurgique et paléontologique du département du Gard, 8vo, Paris, 1876, p. 155.

[2] A. Burat, Les Houillères de la France, 8vo, Paris, 1867, atlas, pl. 23, fig. 1.

and reaches the outer border of the horst near Doué, south-west of Saumur. In this long narrow band the plication of the beds is so intense, that the same horizon of the Culm, bent back upon itself, actually appears three times in the same transverse section, and it was for a long time supposed that the Devonian and anthracite were regularly interbedded. In the most important exposures the beds converge as they dip steeply downwards. Such is the aspect of the crushed extremity of a synclinal fold as it occurs in the Swiss Alps under the most extreme conditions of compression and rolling out. There we meet with Jurassic limestone in gneiss, here with Devonian and Culm; the tectonic process is the same; and thus the band of anthracite on the lower Loire provides us with the trend-line of a mountain chain folded to the north with great intensity, and once undoubtedly of great height.

To the south of the band of granite and gneiss just mentioned, there lies near Chantonnay and Vouvant the coalfield of the Vendée; it is faulted down into the gneiss, and is about 60 kilometers long; it strikes also to the south-east, and, in the midst of the ancient rocks, is accompanied along its whole length by an isolated strip of Jurassic sediments. Grand-Eury assigns it to the middle Carboniferous. Burat observes that the direction of this Carboniferous inlier coincides with that of the south-western border of the Central Plateau, which is accompanied by a series of small exposures of Carboniferous; all of them, like the border itself, striking to the south-east and subsequently finding their continuation in the coalfield of Aubin; this lies transversely across the region uniting the Montagne Noire with the Central Plateau, and strikes right into the region of the Causses [1].

It would thus appear that the south-western border of the Central Plateau must be regarded as one of the Armorican trend-lines, but since according to Grand-Eury these exposures are younger than the Carboniferous of the Vendée, and the distance between the two groups is also great, this question may still be considered as open.

The presence of Variscan trend-lines in the Central Plateau is very clearly marked. The primitive formations may be seen at many places to the west of the Vosges beneath the Mesozoic covering, as for example on the Moselle near Épinal and at the bottom of many valleys right up to the neighbourhood of Bourbonne-les-Bains. To the east of the Morvan the granite also crops out at many places near Sombernon, west of Dijon, and the exposures indicate a subterranean connexion running from the Vosges in a south-westerly direction through the Côte d'Or towards the Central Plateau.

In the interior of the Central Plateau a long 'line' appears as the most important feature.

[1] Burat, op. cit., p. 199.

Near Decize, on the Loire, a fragment of Carboniferous crops out in the plain between two faults. It is the forerunner of a long and continuous series of coalfields, which begin near Sauvigny on the northern border of the ancient mass and extend almost without interruption to Pléaux, south of Mauriac, south of the Dordogne. This line is 160 kilometers in length, or if we continue it to Decize, 220 kilometers; its direction is N. 16° E.; Decize lies a very little further to the east, in accordance with

FIG. 13. *Jurassic limestone pinched into the gneiss at* Farnigen *in the Mienthal,* after Baltzer [1].

the general run of the Variscan arc. 'This remarkable arrangement,' wrote Élie de Beaumont in 1841, 'may be easily explained if we assume that the ancient formations have been folded back upon themselves, and that these Carboniferous deposits are only the remains of once much more extensive Coal-measures which were overpowered by the fold formed on

[1] A. Baltzer, Der mechanische Contact von Gneiss und Kalk im Berner Oberland; Beitr. z. geol. Karte der Schweiz, XX, 1880, atlas in folio, pl. x, fig. 1.

the surface of the ancient rocks[1].' Only a master mind of deep insight could have arrived at this view at that early period; we now recognize a long Variscan trend-line stretching into the more distant and southerly parts of the Central Plateau.

In studying more closely the Coal-measures of the Central Plateau we must now bear in mind that at various parts of its margin, as for instance around the spur of the Morvan[2] as well as towards the south, patches of Carboniferous occur steeply upturned along the marginal fractures, lying sometimes in little trough subsidences, sometimes at the base of downthrown marginal segments, precisely as on the border of the Harz and on the transverse fracture of the Fichtelgebirge near Goldkronach. Among these marginal segments we may doubtless include the coalfield of Autun on the eastern border, which is partly of Permian age. For a knowledge of the inner structure of the mass, however, only those zones are of importance which follow definite lines within the mass itself.

Many years ago, French geologists believed that an intimate connexion existed between the older formations of the Vosges and the Central Plateau. In 1856 Coquand pointed out that the little granite boss of Serre, near Dôle, was a true connecting link between these two great masses, and

[1] '*Saisis dans la ride.*' Dufrénoy et Élie de Beaumont, Explication de la Carte géologique de la France, 4to, Paris, II, 1841, p. 625 et seq. Élie de Beaumont expressly included this line in his 'Système du Rhin,' but he understood by this term not the direction of the folds of the Rhine mountains, but of the Rhine fractures, which cut the strike at an acute angle. The curve of the great arc brings the trend-lines of the folds themselves into the same direction in the Central Plateau as the fractures present on the Rhine. But the truth of the comparison with the infolded synclinals of the Alps appears from the fact that in one of the many small bands of the Carboniferous formation which lie outside this main line, at Langeac on the Allier, not only does the Carboniferous formation of the border dip beneath the gneiss, as happens often enough, but the gneiss lies for a great distance upon the Carboniferous. According to Amiot's description the overthrust mass of gneiss has a length of one kilometer, and attains a breadth of 500–600 meters; one shaft traversed 36, another 80 meters of gneiss, before it reached the Coal-measures, which however are not inverted. For this reason it has been thought that this superposition must be explained by a landslip, but not every overthrust shows the inverted, and at the same time the normal succession; Tournaire, Note sur la constitution géologique du département de la Haute-Loire et sur les révolutions dont ce pays a été le théâtre, Bull. Soc. géol. de Fr., 1869, 2e sér., XXVI, p. 1122, and Amiot, Bassin houiller de Langeac, in Études des Gîtes minéraux, Ministère des Travaux publics, 4to, Paris, 1881, p. 313, atlas in folio, last plate, sections no. 1 and no. 10. The tectonic division of the Carboniferous into two series has been emphasized by Douvillé in Compt. Rend. sur les terrains houillers des bords du Rhin, LXXIV, 1872, pp. 1323–1325.

[2] T. Ebray, Nullité du système de soulèvement du Morvan, Bull. Soc. géol. de Fr., 1867, 2e sér., XXIV, pp. 717–721; Michel Lévy, Note sur le terrain houiller des environs de Montreuillon, le long de la bordure occidentale du Morvan, op. cit., 1879, 3e sér., VII, pp. 914–919; in an essay on the Alpine faults, Ebray says: 'C'est dans l'analyse des failles que doit se trouver la théorie de la formation des montagnes,' op. cit., 1867, 2e sér., XXIV, p. 403.

that a continuous line of dislocation might be followed from the southern end of the Vosges into the Central Plateau.

About the same time Fournet observed that the axis of Mont Saint-Vincent, an Archaean range which reaches the valley of the Saône with a north-easterly direction west of Chalon-sur-Saône, may be followed between the Doubs and the Oignon past Dôle into the neighbourhood of Belfort, and that the disturbances which produced the mountain folds in Saône-et-Loire probably made their effect felt across the Serre near Dôle as far as Giromagny in the Vosges. Fournet speaks of a *chaîne Cébenno-Vosgienne* as opposed to the Jura mountains and the Esterel, and even to the Black Forest[1].

The direction of this line is south-west to north-east. Between Giromagny and Belfort a fragment of Rothliegende forms the southern end of the Vosges. It is accompanied near Ronchamps by a small exposure of Carboniferous, recalling the marginal fragments of the Morvan, the Harz and so many other horsts. From this neighbourhood a series of faults runs to the south-west, and causes a zone of Trias to crop out for a long distance between the Jurassic plateaux. Further to the south-west this dislocation or series of dislocations, which, as it happens, forms the European watershed over the whole of this distance, coincides with the steeper south-eastern border of the granite boss of the Serre; still further to the south-west it coincides with a group of great disturbances running to the south-west, which for a distance of 60 kilometers intersect obliquely the southern prolongation of the Morvan and strike across from the valley of the Saône into that of the Loire. These south-westerly lines bound the important pinched-in Carboniferous zones of Blanzy and Creuzot, which are separated from one another by a trough subsidence between parallel south-westerly fractures; in this the Carboniferous has been let down more than 800 meters, as is shown by borings. These lines reach the valley of the Loire near Digoin, and in the same direction on the other side of the valley another outcrop of workable Coal-measures occurs near Bert; this is let down with the same south-westerly strike, at right angles to the direction of the most northerly part of the Forez. Grand-Eury, it is true, has shown that the Coal-measures of Bert are not of Carboniferous, but Permian age, and they are consequently not the direct continuation of the Coal-measures of Blanzy and Creusot; but the correspondence in position

[1] H. Coquand, Mémoire géologique sur l'existence du terrain permien et du représentant du Grès vosgien dans le département de Saône-et-Loire et dans les montagnes de la Serre (Jura), Bull. Soc. géol. de Fr., 1856, 2e sér., XIV, pp. 13–47, pl. i, in particular p. 40; J. Fournet, De l'extension des terrains houillers sous les formations secondaires et tertiaires de diverses parties de la France, Mém. Ac. Lyon, 1855, V, pp. 239 et seq, p. 287; also by the same, Aperçus sur la structure du Jura septentrional, op. cit., 1861, XI, p. 70; see also Jourdy, Orographique du Jura Dôlois, op. cit., 1872, 2e sér., XXIX, p. 337 et passim.

is so close that we must regard them as the continuation of the Permian beds overlying the great Carboniferous band on the right bank of the Loire[1].

The length of this dislocation, from Bert to the southern extremity of the Vosges, amounts to about 280 kilometers.

It is important to note that this line, which may easily be followed on the geological map, forms the southern end of the Vosges and the marginal fracture of the little horst on the Serre, and then cuts right into the mass of the Central Plateau. As may be seen from the brief account given above it is mainly of post-Permian age, in its north-eastern part even post-Jurassic, but its relations to the folded Carboniferous zones of Saône-et-Loire show that the existing dislocation corresponds to the original strike of the chain, and that it is a true longitudinal dislocation, like the great fracture of Saint-Avold in the region of the Saar.

Élie de Beaumont designates the southern continuation of the Morvan the 'chain of the Tarare.' Although it is broken off on the east by the great fracture of the Rhone valley, yet it is composed of rocks which strike to the south-west, and contains zones of Palaeozoic beds, some of them bearing anthracite, which follow the same direction[2]. The coalfield of Saint-Étienne also extends transversely across the chain, and its strike is not essentially different.

It is not necessary to cite further details. The lines Decize—Sauvigny —Montaigu—Mauriac and Belfort—Serre—Blanzy—Digoin—Bert, as well as the general strike of the zones of the Morvan and the Tarare, show that the whole eastern part of the Central Plateau, together with the volcanic regions as far down as the Dordogne, belongs to the Variscan arc, and that the arcuate ranges towards the middle of the syntaxis show a tendency to describe a more acute angle, that is to say a sharper curve, and to pass from a south-west to a south-south-west direction.

The manner in which the Armorican system enters the Central Plateau is not so clearly marked, but the position of the mountain ranges of the Vendée, and their visible continuation below Poitiers, leave little room for doubt that the smaller western part of the Central Plateau belongs to this system.

If we now piece together the fragments thus found, we see that the syntaxis of the Armorican and Variscan ranges runs right across France. The syntaxis of the overfolded outer borders takes place between Douai and Valenciennes. Further to the south these ranges must once have encountered each other a little east of Paris, their inner branches joining

[1] Grand-Eury, Flore carbonifère du département de la Loire, 4to, Paris, 1877, II, p. 511.

[2] Élie de Beaumont, Explication de la Carte géologique, II, p. 152.

at a more acute angle much further to the south, near the head-waters of the Dordogne.

The great ancient ranges have been levelled down, broken up, and sunk in. It is only with difficulty that we trace by means of the pinched-in ends of the synclinals the position of the great folds by which they were built up. But over these fragments in the south-east of England and the north of France the ancient folding force reawakened after the collapse, and produced the posthumous ranges of the Weald, the isle of Wight, and the Pays de Bray; while over the ancient mountains in the east were formed the Cretaceous synclinals of the Sudetes. In Central Europe another phenomenon occurred. Here, too, more recent movements of folding took place, following the old directions. But these did not find expression above the ancient fragmentary arcs; they were dammed back by the steep fractured margins of the segments left in position or less deeply sunk down. Thus the arcuate folds of the Jura, which deviate but little from the Variscan direction, run past the southern end of the Vosges, where they are checked by the Serre, and beyond the Serre lies Jurassic table-land [1]. In the same way the course of the whole outer border of the Alps is predetermined by the position of the forelying segments.

The map of Europe shows us even more. *The existing contrast between the Alps and the Pyrenees is the same as that which once existed between the Armorican and the Variscan mountains.*

Our knowledge of the relations of the Alps to the Pyrenees has been greatly increased of late years by the efforts of French geologists, and particularly by the investigations of Marcel Bertrand in Provence, which have rectified many previous views: the most important result is the proof obtained by Bertrand that the mass of Hyères (I, Pl. III, 1) is not a horst serving as a buttress and comparable to the Central Plateau, but part of an independent range folded by a force directed towards the north.

We will now trace the course of the outer folds from Geneva to the Mediterranean on the map drawn up by Carez and Vasseur [2].

In the first place it may be observed that according to Bourgeat's observations the folds of the Jura mountains between the valley of Ain and lake Geneva show inversion of the beds seven times in succession, possibly owing to the resistance offered by the Serre near Dôle [3]. Then as the curve of the Jura mountains gradually flattens out, the folds assume towards the south, in the direction of lake Bourget, an almost due north and south strike; but from Chambéry onwards they again turn to the south-south-west, i.e. they again advance towards the plain of the Rhone

[1] Jourdy, tom. cit., p. 376.

[2] G. Vasseur et L. Carez, Carte géologique de la France, Sheets IX and XII.

[3] Bourgeat, Sur la répartition des renversements de terrains dans la région du Jura comprise entre Genève et Poligny; Compt. Rend., 1886, CII, pp. 563–565.

valley; the cause of this deflexion lies in the interior of the chain where the mighty granite mass of the Pelvoux juts out in strong relief. The curve in which the folds bend round this mass becomes continually broader; passing from the south-south-westerly direction, they run first from north to south, then to south-east, until finally ridges appear south of the Pelvoux, which strike due east to west, almost perpendicular to the main direction of the Alps, and yet they correspond only to the independent girdle of the south side of this mass. These transverse ridges, which include the Ventoux and the Montagnes de la Lure, do not again join the outer border of the principal chain of the Alps. A long tongue of Miocene deposits, penetrating the range west of Digne, accentuates still more sharply the independence of the Pelvoux; beyond it, forming a new arc, for the greater part also convex to the south, begin the outer folds of the Maritime Alps, which, closely crowded together, reach the sea near Nice with a fresh deflexion of the strike to the south.

Thus we see first the arc of the Jura flatten out near lake Bourget. Then the girdle of the Pelvoux advances independently, to terminate towards the south in transverse chains, and we are reminded of the fact that the Pelvoux represents the extremity of the granitic outer chain which proceeds from Mont Blanc. Finally the outer border of the Maritime Alps appears, also accompanied by transverse chains, which turn first to the south-south-west and then south to the sea.

This arrangement naturally gives rise to a fairly complicated structure in the several chains. Leenhardt and Kilian have recently described the transverse chain of Ventoux-Lure; it is on the whole an anticlinal, cut through for the greater part by a longitudinal master fault, by which the northern limb is thrown down [1].

The chain of Ventoux-Lure slopes away gently to the south, and is followed in this direction, between the Durance and the Rhone, by a new transverse chain, the Léberon; in the western continuation of this lies the chain of the Alpines, which terminates near Arles.

The approximately east to west strike is continued up to the chain of Sainte-Baume, east of Marseilles; which, as Bertrand has shown, is completely overfolded to the north for a distance of 15 kilometers. Within this chain however, that is, towards the south, there follows another and yet more mighty overthrust, which begins in the neighbourhood of Saint-Cyr, and further to the east, near Le Beausset, north-west of Toulon, is

[1] F. Leenhardt, Étude géologique de la région du mont Ventoux, 4to, Montpellier et Paris, 1883, 273 pp., map; W. Kilian, Note préliminaire sur la structure géologique de la Montagne de Lure, Basses-Alpes, Compt. Rend., 1886, CII, pp. 1407–1409; and Note géologique sur la Chaîne de Lure, Feuille des Jeunes Naturalistes, Paris, 1887, XVII, pp. 48–55, section. The position of this chain led me to assign it to the girdle of the Pelvoux; Kilian compares it with the more southerly transverse chains.

finally carried so far that a completely crushed mass of Trias is driven over the upper Cretaceous, with a horizontal displacement of at least 6 kilometers, as estimated by Bertrand[1]. We are now in that independent folded range, mentioned above, to which belong, according to all appearances, all the heights from the mouth of the Rhone to Antibes.

A very complicated syntaxis thus occurs in the south-east of France; folding movements approach one another, directed on the south border of the Pelvoux from north to south, on the south border of the Maritime Alps likewise from north to south, and further on, along the Var, from east to west, then on the outer border of the chain of Hyères from south to north and on the Var from west to east. This gives rise to a general folding of the intervening land with a very variable degree of intensity, resulting in the formation of chains of heights, such as the Alpines and the Léberon, in the more open parts of the syntactic region, and to an ever closer crowding and crushing of the convergent folds, as the border of the Alps and that of the chain of Hyères approach one another from Castellane to the Var.

Bertrand justly considers the Maures or the chain of Hyères as an important and independent link standing in the space which at present separates the Pyrenees from the chain of the Alps. It is evident that the Alps and the Pyrenees do not approach each other in a simple V-shaped syntaxis. It is clear also that on the south side of the Pelvoux and the Maritime Alps the folding force, which elsewhere in the Alps is always directed to the north, turns just as completely to the south as it does in the extremity of the Carpathians in the south of Transylvania. Perhaps we may even succeed in showing that the syntaxis on the lower Var is another though minor example of that direct opposition of the tangential movements, which is displayed on so grand a scale between the Himálaya and the Burmese chains on the Brahmaputra (I, p. 452).

Thus several arcs crowd together in the south of France. The junction with the Pyrenees is not to be seen, but the plan of the mountain chains lies before us, and we observe the remarkable likeness of the younger to the older mountains.

From this it results that the prevailing tangential movement to the north, which is characteristic of the Alps and Pyrenees, affected Northern Europe, as far as the Caledonian folds extend, before the Devonian, and the whole of Central Europe before the Carboniferous. If we consider the ancient syntaxis in the Central Plateau of France and its position between the Alps and the Pyrenees, we are even justified in speaking of

[1] M. Bertrand, Coupes de la chaîne de la Sainte-Beaume, Provence, Bull. Soc. géol. de Fr., 1885, 3e sér., XIII, pp. 115–150, map; and Rôle des actions mécaniques en Provence, explication de l'anomalie stratigraphique du Beausset, Compt. Rend., 13 Juin 1887, CIV, p. 1735.

the *Variscan Alps* and the *Armorican Pyrenees*: understanding by these expressions the older pre-Permian chains.

In the horsts, as we have said, *an older Europe stands disclosed* (I, p. 203). We are now in a position to trace its leading features. A great folded system of lofty mountains—proceeding from Central France, out of a region indicated at its northern end by Douai and Valenciennes, and at its southern end by the upper course of the Dordogne—runs in arc-like curves to north-west and west-north-west. This system embraces the west and north of France, the south of England and the narrow zone in South Wales and Ireland. In Brittany, Cornwall, and Bantry bay, its folds may still be seen running out towards the Ocean, beneath which their last ruins lie concealed.

From the same region of syntaxis other great ranges run in arcs to the north-north-east and north-east; these comprise all that part of the existing continent comprised between the southern end of the Black Forest to the coalfields on the Ruhr, the Harz, the Erzgebirge, and the Sudetes.

The ancient chains collapse and new terrestrial folds approach them from the south. The Pyrenees and Alps follow the old directions, and adapt themselves to the outlines of the ancient fragments still projecting which check their course. The Carpathians however, restricted by no fractured border, ride over the ancient mountains.

Thus it happens that in the syntaxis of the Central Plateau of France the chief tectonic lines converge towards the south, but in northern and central Bohemia, which lie within the arc, towards the north; so that in the former case the characteristic figure is a V, in the latter the same inverted Λ. For the long lines of fracture of the Silurian trough of Bohemia, with which Krejci has made us acquainted, and the fault at the foot of the Erzgebirge, as well as the line of fracture of the Daubrawa as far as Elbe-Teinitz and the faults at the foot of the Riesengebirge, are longitudinal lines running approximately in the same direction as the fragment of arc which they affect.

Between these arcs, however, there lies, strange and unexplained, the mountain fragment of Bioa, striking to the north-west and folded according to Gümbel to the north-east, namely the Bavarian forest with the south-western marginal district of Bohemia and opposite to this the great gneiss basin of the Waldviertel in lower Austria[1], with its strike directed to the south-south-west. Whether these are the traces of a still older syntaxis, or what other significance they possess, further investigation must decide.

10. *The Iberian Meseta.* In an earlier passage we distinguished, in

[1] F. Becke, Die krystallinischen Schiefer des niederösterreichischen Waldviertels; Sitzungsber. k. Akad. Wiss. Wien, 1881, LXXXIV, p. 546; cf. also the earlier observations of Holger, Czjzek, Lipold, and others.

accordance with the views of MacPherson, three elements in the Iberian peninsula, namely: the Meseta, composed chiefly of ancient rocks; the Betic cordillera, a folded chain, in the south; and the Pyrenees, also a folded chain in the north-east.

The chain of folded mountains which forms the north coast of western Africa swerves completely round in Morocco, from east and west to south-east and north-west, and finally to south and north, and with this northern strike reaches the straits of Gibraltar. At the Râs Torf (cabo Negro) and near Ceuta, mica schist and ancient clay slate crop out; further to the west, above Tétuan, Trilobites have been found; then follows a zone of red sandstone; west of this the Mesozoic limestone band of the Jebel Musa is continued into the Rock of Gibraltar; still further to the west is Flysch, which forms cape Spartel. This mountain arc closes the Mediterranean, turns completely round in Spain to the east-north-east, runs in this direction up to Alicante, and forms all that part of the country lying south of the Guadalquivir. This is the Betic cordillera, traversed by great flaws (I, p. 227).

Just as the folding of the Alps is checked by the fractured borders of the opposing horsts, so the Betic folding is arrested along the Guadalquivir, and dammed back by the southern border of the Meseta; this has been shown in a convincing manner by MacPherson [1].

Near Villa do Bispo on the Atlantic coast, a little to the north of cape St. Vincent, the southern edge of the Meseta is visible; Mesozoic beds accompany it in the south. It runs fairly parallel to the coast through Algarve to the mouth of the Guadiana, accompanied so far by the Mesozoic zone; thence it stretches almost in a straight line to the east-north-east a long way into the interior, forming the northern slopes of the valley of the Guadalquivir and at the same time the southern slope of the sierra Morena further to the east (I, p. 294). The way in which the margin cuts across the strike of the ancient rocks of the Meseta along the Guadalquivir led MacPherson to recognize in it a mighty fracture; this is the *fault of the Guadalquivir*.

Calderon's instructive representation of the structure of the Meseta and Botella's geological map show the polyhedral outline and peculiar configuration of this great horst [2].

[1] J. MacPherson, Breve noticia acerca la especial estructura de la Peninsula Ibérica, An. Soc. Españ. Hist. Nat., 1879, VIII, pp. 5–26; and Uniclinal Structure of the Iberian Peninsula, 8vo, Madrid, 1880. For the transverse fracture in the direction of the strike on the south border of the Meseta see in particular his little map in the Estudio geológico y petrográfico del Norte de la Provincia de Sevilla, Bol. Com. Map. Geol. Españ., 1879, V, sheet G; for the Betic flaws, C. Barrois et A. Offret, Sur la constitution stratigraphique de la chaîne Bétique, Compt. Rend., 1886, CII, p. 1341.

[2] S. Calderon y Arana, Ensayo orogénico sobre la meseta central de España, An. Soc. Españ. Hist. Nat., 1885, XIV, pp. 131–172; F. de Botella y de Hornos, Mapa geológico de España y Portugal, I: 2,000,000, fol., Madrid, 1879.

The fault of the Guadalquivir runs down as we have seen from the east-north-east, passes close to the mouth of the Guadiana, and is continued through Algarve into the vicinity of cape St. Vincent. The Culm, which forms the south-western part of the Meseta in southern Portugal, dips towards the Atlantic Ocean beneath recent Tertiary beds, as may be seen on the map by Ribeiro and Delgado, but along the coast itself it again crops out from under these beds. It is only further to the north, from central Alemtejo onwards, that the western outlines of the Meseta are more clearly defined. Its rocks, striking to the north-west, advance in sharply outlined ridges, which run in rias lines, as it were, into the Portuguese plain; as examples, we may mention in particular the granite ranges of Evora. Near Tancos on the Tagus the boundary again becomes rectilinear and sharply marked; it runs thence to the north-north-west, a little to the east of Thomar and Coimbra, and reaches the sea not far south of Oporto [1].

From this place onwards the rocks of the Meseta form all the iron-bound coast of the north-west far across to the Asturias, where the Cretaceous mountains of Oviedo, and then of Santander and Bilbao, join the Pyrenees with an east to west strike. The north-eastern edge of the Meseta, however, is bordered by a broad zone of downthrown Mesozoic patches which extend from Cuença to the gulf of Valencia and cabo de la Nao.

The structural peculiarities of this great horst are especially apparent in the north-west. Fortunately there is a series of excellent treatises on this region; we will only mention those of Wilhelm Schulz and Charles Barrois. Barrois in particular has described in a masterly manner the chief structural features of Galicia and Asturias, and the remarks which follow are borrowed from his monograph [2].

The most ancient rocks crop out in Galicia; these are mica schists, green schists and serpentine, as well as gneiss and intrusive granite. They strike almost north to south, but with a gentle curve to the west; in the north of Galicia the beds dip to the north-west, in the centre to the west, and in the south to the south-west. The dip of the beds is thus directed *beneath the arc and towards the exterior* so to speak. On the boundary of Asturias, Cambrian deposits begin, broken through in places by granite bosses, which play a passive part in the movements of the mountains.

[1] C. Ribeiro e J. F. Nery Delgado, Carta geologica de Portugal, 1 : 500,000, fol., Lisboa, 1876. The small granite masses near Cintra do not belong to the Meseta, but, according to Choffat, are of post-Cenomanian age; P. Choffat, Âge du granit de Cintra, Jorn. Sci. Math. Ac. R. Lisb., 1884, XXXIX.

[2] G. Schulz, Descripcion geológica de la provincia del Oviedo, Asturias, 4to, Madrid, 1858, and atlas; C. Barrois, Recherches sur les terrains anciens des Asturies et de la Galicie, Mém. Soc. géol. Nord, II, Lille, 1882, 630 pp. and plate. Among earlier works must be especially mentioned A. Paillette, Recherches sur quelques-unes des roches qui constituent la province des Asturies, Bull. Soc. géol. de Fr., 1845, 2e sér., II, pp. 439–482.

The dip of the Cambrian beds is precisely the same as that of the older rocks of Galicia, that is beneath the outer arc, and the Archaean rocks are consequently driven over the Cambrian. Within the Cambrian, however, there follow conformably, with the same dip, a Silurian, a Devonian, and finally a Carboniferous arc, always with inverted bedding and increasing constriction of the arc, so that on the Rio de Pervia the northern branch of the Devonian arc reaches the sea with a north-easterly strike, and the Carboniferous is compressed into an ellipse striking from west to east. The mighty curve of a great range is thus visible, and within the curve imbricated structure. Towards the west, in Galicia, the most ancient rocks form the outer arc; towards the east, in Asturias, the Carboniferous beds,

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beds, it is true, have also been folded subsequently, and in the same direction; Barrois recognizes 'the fact of the recurrence of the same movements at different epochs[1].'

In the province of Oviedo there now follows unconformably the whole Mesozoic series, together with the Nummulitic limestone, striking to the east and folded to the north; it is regarded as the western part of the Pyrenees and does not concern us here.

It is the outer part of the basin of Asturias, and in particular the mountains of Galicia, which run down to the south-south-east and south-east into the great Meseta. A large number of separate works by the Geological Survey of Spain, now making such admirable progress, show us the further course of the rocks in the same direction. In places, it is true, patches of Cenomanian rest on the ancient mass, as in Bohemia, while the central and eastern part of the Meseta are covered far and wide by Tertiary fresh-water beds. Notwithstanding this we observe the following facts. The ranges running down from Galicia through Tras-os-Montes and Beira Alta are formed of ancient folded systems accompanied by great exposures of granite. The direction is south-south-east to south-east. To the south of Salamanca a mighty branch is given off in virgation to the east and east-north-east. It consists chiefly of granite and gneiss, and forms the sierra de Gredos and sierra de Guadarrama. The other ranges, however, continue their course to the south-east, and form a number of almost parallel folded ranges of great length, closely packed and in many cases slightly convex to the south-west. They consist of Archaean and Palaeozoic rocks, including a part of the Carboniferous, as in Asturias. The course of this arc may be best indicated by a line drawn from Oporto to the south-east past Alcantara, then a little west of Cáceres, past Don Benito, then, with a slight bend, through Pozzoblanco to the sierra Morena. This line is especially characterized by long granite ridges. Thus with a strike directed in general to the south-east, the folded ranges of the Meseta reach the Guadalquivir, where they are broken off transversely, as we have already seen.

The bands of granite in this intensely folded mountain system were for the most part intruded, according to MacPherson, during the Carboniferous period. Here also the upper beds of the Carboniferous lie unconformably on the folded region, as in Asturias, and the general structure of these mountains thus dates, like that of the Armorican and Variscan systems, from the last days of the Carboniferous period.

These folded ranges striking to the south-east are now continued into the south of Portugal and form the whole south-west of the Meseta. They are the same ranges which have already been described as advancing with a north-west trend into the Portuguese plain in Alemtejo, like the granite

[1] Barrois, Mém. Soc. géol. Nord, 1882, op. cit., p. 604.

of Evora. Further south, the strike turns somewhat more to the west-north-west, and in the south of Alemtejo, between Beja and Mertola, where, according to Delgado, the prevailing dip is to the north-east, imbricated structure would seem to occur.

In the Spanish province of Huelva lie the famous mines of Rio Tinto; the strike is N. 70° W., and thence, according to Delgado, the copper pyrites may be followed for a distance of 145 kilometers, to Aljustrel in Portugal, the strike gradually turning to N. 50° W. If, however, we include the pyrites of Caveira near Grandola, then the length of the band would amount to 183 kilometers[1].

These great arcs of the south-western Meseta appear in fact to have been folded towards the south-west, and MacPherson's assertion therefore applies to them, i.e. that a considerable part of the mountain ranges of the Iberian peninsula has not been thrust to the north like the Alps, but to the south like the folded ranges of North Africa.

We now find ourselves confronted by a number of the most difficult questions.

Let us first consider the relation of these arcs to the Betic Cordillera.

The older folds reach the fault of the Guadalquivir with a south-easterly strike; the Betic folds strike to the east-north-east, or almost at right angles to them. In precisely the same way, with a transverse strike, the Carpathians approach the Sudetes. Here, on the Guadalquivir, however, it is quite clear that it is not the direction of the older folds, but that of the fractured border, which determines the course of the succeeding younger folds. Beyrich arrived at the same result many years ago in the case of the Sudetes.

Let us now glance at the position of the Asturian basins. These basins with imbricated structure, which dip beneath the outer arcs, indicate in any case the deflexion of a folded range. It is the outer arcs of the southern flank which we have followed from Oporto up to the Guadalquivir, and through Alemtejo into the neighbourhood of cape St. Vincent. In just the same way the younger folded chain, after crossing from Africa, bends round in Gibraltar to form the Betic cordillera, and if we could make a horizontal section, some thousands of feet below the western end of the Mediterranean, we should probably find an arrangement of the rocks similar to that in the Asturian basins. Between Ceuta and Tangier the beds run from south to north, at right angles to the straits of Gibraltar, exactly like the rocks in western Galicia, save that here there is more of the outer and less of the inner arc to be seen, while in the north only the inner arcs are visible.

Since we know that the mountains of North Africa are only the last

[1] J. F. N. Delgado, Sobre a existencia do terreno Siluriano no Baixo Alemtejo; Mem. Ac. Sci. Lisb., 1876, p. 12, note.

of the numerous arcs which mark the southern boundary of Eurasia, and that it is these boundary arcs which retain in Europe the curvature and folding to the south characteristic of Asia, we obtain the following result:—

The bending round of the westernmost mountain range of Eurasia, where the folding movements pass from a northerly to a southerly direction, takes place at present near Gibraltar; but towards the close of the Carboniferous period another great mountain system had previously arisen, in which the change in direction of the folding movement from north to south manifested itself in the place now occupied by the Asturian basins, i.e. about eight degrees of latitude north of the existing circumflexure.

This ancient chain was subsequently worn down and broken up, and the new arc was arrested on the Guadalquivir by the fractured border. The reconstruction of the continent on the old plan is much more clearly manifest here than in Central Europe. The Pyrenees appear to have followed the Armorican arc, and the Alps the Variscan, simply as a result of the persistence of the southern thrust acting within the space included by the residual fragments, but this is not all, and indeed an entirely new problem now presents itself. For we have here not simply an ancient mountain range followed by a new one, folded in the same direction, but an ancient circumflexure followed by a new circumflexure. The region of recurvature has been displaced southwards and we do not find, as between the Black Forest and the Jura, folds driven to the north-north-west, following other folds driven in precisely the same direction, but along the fault of the Guadalquivir, the Meseta is formed by that branch of the ancient mountains which is folded to the south-west, while opposite to it lies the branch of the Betic cordillera, folded to the north-north-west.

The question at once suggests itself whether the ancient Iberian range is not a fragment of the Armorican arc. In age they correspond; the rocks of Asturias resemble those of Cornwall and Brittany, and both the folded regions are certainly continued far beneath the sea; but whether they meet or unite, and if so in what manner, it is impossible to determine.

In the Meseta it is again the upper divisions of the Carboniferous which correspond with the period of greatest tectonic movement. In the last century, when Werner drew for the first time the limit between the 'transition formations' (Uebergangsgebirge) and the 'horizontal formations' (Flötzgebirge) he had no other line of demarcation in mind than that afforded by the great discordance within the Carboniferous formation in Saxony. It is with the same meaning that the term 'Flötzgebirge' appears again on Lossen's map of the Harz. Everywhere we find this limit. The Coal-measures of Ostrau, which form part of the Sudetes, stand in the same relation to those of Rossitz in Moravia, as those of Sama to the transgressive Coal-measures of Tineo in Asturias, and in Nova Scotia we meet with the same limit on the other side of the Ocean.

11. *Survey of the pre-Permian ranges in Europe.* The original continuity of the Armorican horsts, or at least of some of them, was, as we have seen, rightly recognized by English and French geologists many years ago. A perception of the continuity of a great part of the Variscan horsts also is evident enough in Lossen's instructive work on the nature of the mountain cores which lie between the Ardennes and the Altvater. This treatise also shows us how impossible it must have been in the time of L. von Buch—when observation was not yet sufficiently advanced to distinguish lines of fault from the strike of the folds—to form any conception of the structure of the land which would correspond to the existing state of our knowledge. A large part of the Armorican horsts have been grouped together by Penck also under the name of the 'Central German Alps,' with recognition at the same time of their Carboniferous age[1].

The Variscan chain makes its appearance first on the northern border of the Carpathians and strikes to the north-east and north-north-east in Moravia, as though it had here experienced a deflexion similar to that of the end of the Carpathians, and as though some trace of the tectonic relations of the Iberian mountains were about to recur. Then the range, as it forms the Sudetic arc, turns forward to the north, north-north-west, and finally north-west, and so passes to the Elbe.

Next follow with a north-east to east-north-east trend the mountains of Saxony, namely the Erzgebirge and Fichtelgebirge, the Saxon folds up to Leipzig and those folded fragments which are preserved in the Thüringerwald and Frankenwald. These all belong to the inner Variscan zones. Their continuation forms the Black Forest, the Vosges, and the exposures of older formations in the Odenwald and Spessart; the strike of the folds is directed to the north-east, and they proceed to the south-west, past Dôle to the Central Plateau of France. Meanwhile the strike gradually passes over from north-east and south-west to north-north-east and south-south-west, as is clearly shown by the patches of Coal-measures which occur pinched into the gneiss as far as the upper Allier. The outer zones of the arc are visible, apart from the Sudetes, in the Harz and in the Devonian mountains of the Rhine, from the Taunus up to the Coal-measures in the north. The overthrust outer border is only to be seen between Valenciennes and the neighbourhood of Aix-la-Chapelle and in a part of the coalfields on the Ruhr.

The Armorican range rises in the western part of the Central Plateau; in the Vendée, Brittany, and the Cotentin, it trends first west-north-west and

[1] K. A. Lossen, Ueber das Auftreten metamorphischer Gesteine in den alten paläozoischen Gebirgskernen von den Ardennen bis zum Altvatergebirge, und über den Zusammenhang dieses Auftretens mit der Faltenverbiegung (Torsion), Jahrb. k. preuss. geol. Landesanst., 1884, pp. 56–112 (on torsion cf. here note 2 on p. 101); A. Penck, in Länderkunde des Erdtheils Europa, published by A. Kirchhoff, 1886, I, p. 313.

then, as it proceeds towards the Ocean, more and more to the west. The outer zones are visible in the Devonian reef near Boulogne, in Cornwall and Devon, and in the southernmost parts of Wales and Ireland. The overthrust outer border may be traced in a west-north-west direction from Douai to Calais. The posthumous folds of the Weald indicate the continuation of the range. The overthrust outer border is next again seen on the north side of the Mendips; it strikes across the Bristol channel towards St. Bride's bay in the south-west of Wales, and thence through the south of Ireland. The trend turns, towards the Atlantic Ocean, from west-north-west to west, and finally, near the sea, almost to west-south-west.

The Iberian fragment is thrown into folds which trend in a gentle curve from Galicia and the north of Portugal to the south-south-east and south-east, and with frequent overfolding to the south-west, but they are abruptly cut off along the Guadalquivir, opposite the Betic cordillera. They give off a branch which forms the sierra de Guadarrama, but in Asturias their inner parts bend round so completely that a peculiar basin-like structure is produced, with the older members situated on the exterior of the basin, but thrust over the younger members of its interior in great flakes. Thus the Iberian fragment reaches the sea, striking in Galicia to the north and north-north-east and in Asturias to the north-north-east, north-east, and finally east-north-east. Its connexion with the Armorican range is not known.

It thus appears that towards the close of the Carboniferous period great mountain ranges arose in Central Europe, which were folded towards the north, like the existing Alps. They then collapsed and their fractured borders resisted the development of the new folds, which now form the Betic cordillera, the Pyrenees, the Alps, and the Carpathians. That fragment which still exhibits the ancient syntaxis, the Central Plateau of France, now separates the arcs of the Alps from the Pyrenees. The basin structure of Asturias is repeated in the curvature of the chain near Gibraltar.

In this way Central and Western Europe were reconstructed for the second time.

12. *European islands.* The significance of the islands of the Atlantic and of the archipelagos of Europe is apparent from the facts which have already been described.

The *Orkneys* and the *Shetland islands* are parts of the pre-Devonian Caledonian range which strikes towards Norway.

The inner *Hebrides* represent in part comparatively recent volcanos: the outer Hebrides together with the adjacent coast of Scotland correspond in position and structure with the *Lofoten* islands and the east coast of the Vest fjord.

Waigatsch and *Nova Zembla* are fragments of an independent folded range which is syntactic with the northern Ural at Konstantinov-Kamen.

Spitzbergen together with the neighbouring islands up to *Franz-Josef Land* and *Bear island* are relics of a plateau with Devonian beds lying horizontally, as in Scotland.

Jan Mayen is of recent volcanic origin.

The *Faeröes* are remnants of ancient volcanic flows with intercalations of Tertiary plant-bearing beds.

The great island of *Iceland*, finally, presents an older volcanic substructure similar to that of the Faeröes, on which recent volcanos are superposed. The substructure contains plant-bearing beds, and is of middle Tertiary age. This part corresponds to the similar series of the Faeröes and Greenland. The subsequent eruptive formations, however, belong to different periods, as is indicated by the distribution of the glacial markings and an intervening inundation of the island. The volcanic activity must have persisted from the middle Tertiary period down to the present day.

Many investigators have visited Iceland since Eggert Olafssen and Bjarne Povelsen made their observations on the natural history of the island, between the years 1752 and 1757[1]. But, not to speak of the great difficulties due to climate, the impracticability of the country, and its extent, these passing visits were the less likely to lead to a clear insight into the structure of the island since the investigators as a rule concentrated their attention on general questions concerning the nature of the volcanic phenomena. But now, since an Icelander, Thoroddsen of Reykjavik, has devoted himself to the geology of his country and, with as much perseverance as ability, is tracing out, year after year, the fundamental features of its structure, the facts are beginning to appear with ever-increasing clearness. At the same time it becomes more and more apparent that the ancient volcanic substructure is traversed like Scania and Spitzbergen by fractures which cut it up into horsts and troughs, and that with these fractures the more recent manifestations of volcanic activity are connected. Permission has been kindly granted me to borrow from Thoroddsen's as yet unpublished observations the following information:—Not only is Snaefell's Sýsla, the great peninsula half-way down the west coast, a true horst bounded on the north and south by lines of fracture, and not only is Faxa Fjördr on the south side, together with the depression which continues it into the interior, an area of subsidence—facts which have been already mentioned by Keilhack[2]—but Breidi Fjördr in the north of

[1] Eggert Olafssen og Bjarne Povelsen, Reise igjennem Island, 1752–1757, 2 vols., 4to, Sorö, 1772 (translated into English, 2 vols., 1800–1805).

[2] K. Keilhack, Beiträge zur Geologie der Insel Island, Zeitschr. deutsch. geol. Ges., 1886, XXXVIII, pp. 376-449; on p. 392 there is a transverse section of the fault trough on the south side of the Skard-sheidi, i. e. on the south side of the great horst of Snaefell. The communications of Herr T. Thoroddsen, of Reykjavik, I owe to the intervention of

the peninsula, as well as Húna Flói on the north coast of Iceland together with Steingrines Fjördr, also owe their origin to subsidences, which have evidently had the most pronounced effect in determining the contour of the table-land. The southern range of Reykjanes is also a horst, on both sides of which movements appear to have occurred in quite recent times. Nowhere in the south of Iceland do earthquakes occur so frequently as on the south side of this peninsula.

Without anticipating further the publication of Herr Thoroddsen's results, it may be pointed out that the discovery of these plateau fractures, and the breaking up of the island into horsts, steps, and troughs, while of great local interest, suggests questions of a more general kind. In the first place we see in the progress of these subsidences the continuation of the processes which have formed the surrounding part of the Ocean. Further it must be borne in mind, that all the middle Tertiary rocks of the substructure contain no organic remains except land plants, and have certainly been formed above the sea. A little patch of marine deposits found near Halbjarwarstadir, north of Húsavik on the north-east coast, is placed by Mörch on the horizon of the English Crag [1]: in addition, glacial or post-glacial shell beds which attain a height of about 200 feet are met with in many places. The island was, therefore, partially inundated at a later time. Thus in Iceland the question is very definitely suggested whether the movements of the solid land are sufficient to explain the displacements of the coast line or whether we must invoke independent changes in the level of the sea.

13. *Western Africa.* The scant observations hitherto made on the north-west coast of Africa leave us free to suppose that Tertiary deposits such as we have studied on the west coast of Spain may exist here also. From lat. 29° 30′ to 28° N. Duro found the coast formed entirely of beds of light-coloured sandstone, undermined by the sea. Similar beds exist in the Wady Draa. Scaling the cliffs along the coasts we see before us an illimitable plain [2]. The conclusion that the middle Tertiary sea covered the western Sahara seems irresistible and the observations of Lenz on his journey to Timbuctoo accord well with such a view.

The adjacent islands are volcanic and some of them bear still active craters. An independent series underlies them. L. von Buch distinguishes in the Canary islands a foundation of older volcanic rocks on which the more recent volcanos were seated. We owe to Doelter the unexpected

Professor Nathorst of Stockholm; cf. also T. Thoroddsen, Eine Lavawüste im Innern Islands, Peterm. Mittheil., 1885, XXXI, pp. 285, 327, pl. xiv.

[1] O. A. L. Mörch, On the Mollusca of the Crag formation of Iceland; Geol. Mag., 1871, VIII, pp. 391–400.

[2] C. F. Duro, Exploración de una parte de la Costa Norueste de Africa; Bol. Soc. geogr. Madrid, 1878, IV, pp. 184–199.

discovery that Majo, one of the Cape de Verd islands, is formed to a large extent not of volcanic rocks but of slate and limestone, the remnant of an ancient continent[1]. We have already pointed out that marine deposits of middle Tertiary age, having the characters of the first Mediterranean stage, contribute to the structure of Madeira and Porto Santo, as well as of Santa Maria, the most southerly of the Azores (I, p. 288).

Remote from all these islands, in space as in the nature of their rocks, are the five black reefs lying far out to sea in lat. 0° 55′ N. which are designated together as Saint Paul's rocks. Darwin did not regard them as volcanic islands, and Renard has shown, from the specimens brought home by the Challenger Expedition, that they consist of peridotite[2].

As regards a very large number of the volcanic islands of the eastern half of the Atlantic, there is good reason to suppose that the volcanos stand on a common foundation. This was the view of L. von Buch and Hartung, and has been supported by Calderon in a recent review of the question[3].

Of this region we may affirm, with much greater certainty than of the north, that the visible volcanic islands represent only a small part of extensive volcanic regions covered by the sea. The numerous indications of submarine activity—such as sudden shocks, eruptions of smoke, or unexpected shallows, which have been recorded between long. 18° and 26° W., especially in the neighbourhood of the equator—led Daussy as early as 1853 to suspect the existence of a submarine eruptive region situated in about lat. 0° 22′ S. and long. 22° W.[4]

The leaf-bearing Tertiary beds which appear in the Hebrides, the Faeröes, and in Ireland, and everywhere in the north accompanying the basaltic lavas, are not to be found on these islands. To complete the contrast, while the Tertiary beds of the north are never marine, those of the islands are exclusively so; Tertiary beds, however, are restricted to some of the islands already referred to.

Our knowledge of the geological structure of Senegambia and Guinea is extremely fragmentary. Gürich's survey of existing observations shows, however, that the same structure which it seemed possible to trace (I, p. 398) from the far south up to Pungo Andongo (lat. 9° 24′ S.) probably prevails as far as the lower Faleme and the upper Senegal, as well as over a very

[1] C. Doelter, Die Vulkane der Cap Verden und ihre Producte, 8vo, Gratz, 1882.

[2] A. Renard, Description lithologique des récifs de Saint-Paul; Ann. Soc. Belge de Microscopie, 1882, 53 pp.

[3] D. S. Calderon, Edad geológica de las Islas Atlánticas, y su relación con los Continentes, Bol. Soc. geogr. Madrid, 1884, IX, pp. 377–399; see also Milne Edwards, Compt. Rend., 1883, XCVII, p. 1389.

[4] P. Daussy, Note sur l'existence probable d'un volcan sous-marin, situé par environ 0° 20′ de lat. sud et 22° 0′ de long. ouest, Compt. Rend., 1853, VI, p. 512, reproduced with a map showing the distribution of the observed shocks, in Mallet's fourth Report upon the facts and theory of Earthquake Phenomena, Rep. Brit. Ass., 1858, p. 20 et seq.

large part of the alluvial river basin of the Djoliba [Niger] and the Binue. Folded Archaean rocks, fairly various, accompanied here and there by clay slate of unknown age, form a basis surmounted by great horizontal masses of red sandstone. These are frequently broken up into table mountains and do not appear, in the regions studied by Gürich, to exceed a height of 300 meters. Gürich is inclined to regard the exposures of Foyaite in the Los islands, and the olivine gabbro of Freetown (Sierra Leone), as interbedded with the horizontal sedimentary strata [1].

These characters recur with marvellous uniformity; we recognize them in the descriptions of the banks of the Congo by Leng and Baumann, and they are clearly shown in Pechuël-Loesche's geological map of the western Congo region. It is near Kalubu, far below Stanley Pool, that the region of the horizontal red sandstone begins, which extends into the interior beyond the Pool [2].

To the north of the equator, however, a new element appears, the zone of middle Cretaceous and Tertiary marine beds, which, as it would now seem, border almost the whole coast up to the Cunené. These were first discovered at a few widely separated points by Giebel and Lenz (I, p. 398). Since then similar Cretaceous beds have been described by Malheiro and Choffat in the neighbourhood of Benguela. Here red sandstone, containing some gypsum, sulphur, and copper, rests upon gneiss, and is followed by Cretaceous beds [3]. Still further to the south, on the coasts of Mossamedes, Anchieta describes the Cretaceous and Tertiary sediments as a selvage, hardly 100 meters high and 20–25 kilometers broad, formed of horizontal beds which are bounded towards the interior by gneiss [4].

On the lower Khuiseb, ancient folded schists strike according to Stapff north-west and south-east. In Angra Pequeña jointed limestone, sometimes still in thick beds, rests, according to Schenk, on the horizontal sandstone which covers the Archaean foundation; here great plateau fractures occur, which correspond to the course of the coast and are probably only

[1] G. Gürich, Beiträge zur Geologie von West-Afrika, Zeitschr. deutsch. geol. Ges., 1887, XXXIX, pp. 96–135; see in particular A. Pomel, Le Sahara, 8vo, Alger, 1872, pp. 23 et seq., and for the coast regions, O. Lenz, Verh. k. k. geol. Reichsanst., 1878, pp. 52, 119, 148, 168, et passim; also Geologische Karte von West-Afrika, Peterm. Mittheil., 1882, pl. i; C. W. Gümbel, Beiträge zur Geologie der Goldküste in West-Afrika, Sitzber. k. bayr. Akad. 1882, pp. 170–196; Chaper, Note sur la géologie de la possession française d'Assinie, Bull. Soc. géol. de Fr., 1885–1886, 3e sér., XIV, pp. 105–112.

[2] Pechuël-Loesche, Zur Geologie des westlichen Congogebietes; Deutsche Rundschau f. Geogr. und Stat., published by F. Umlauft, Vienna, 1886, VIII, pp. 289–293, map. In the region of the coast asphalt is said to occur.

[3] P. Choffat, Note préliminaire sur des fossiles recueillis par M. Lourenço Malheiro dans la province d'Angola; Bull. Soc. géol. de Fr., 1887, 3e sér., XV, pp. 154–157.

[4] J. de Anchieta, Traços geologicos da Africa occidental portugueza; Bol. Soc. geogr. Lisboa, 1885, 5a ser., no. 9, pp. 525–529.

the continuation of the remarkable plateau fractures of Cape Colony, previously described [1].

All these observations, though scattered over large areas, confirm the view that Africa, with the exception of its north-western part, is an ancient table-land, and the presence of the middle Cretaceous transgression adds another remarkable feature to its resemblance with other table-lands and horsts situated far away from it.

14. *The East of Central and South America.* From the descriptions given in previous chapters of the tabular structure of Florida and the resemblance between the cordillera of the Antilles and the borders of the western Mediterranean or of the Hungarian plain, we may deduce the structure of the coast of Central America.

A great variety of marine beds of Tertiary or still more recent age occurs in this region, and the classing together of calcareous deposits of different age has led to many erroneous conceptions with regard to elevations of the land, said to have occurred in quite recent times. We may take this opportunity to recall the European characters presented by the Mesozoic and Tertiary marine faunas of this part of America (I, p. 522).

As the subject is of some importance in connexion with one of the following chapters we will now illustrate the structure and succession of strata in the outer Antilles by means of an example, selecting for this purpose the island of Antigua and making use of information drawn from the descriptions given by Purves [2].

Antigua has the form of a triangle; its longest side is turned to the north-east, facing the Ocean, and measures 25 kilometers. On this side the submarine slope is very gentle; on this side also the most recent beds occur, which are continued into Barbados, only 48 kilometers distant and separated by no greater depth than 30–40 fathoms. To the south-west, on the other hand, the fall is very rapid, and towards the island of Guadeloupe, which is not further away than Barbados, we soon meet a depth of 300 fathoms. The south-western part of Antigua is mountainous and attains a height of 1,400 feet; the north-eastern part is hilly, and between 300 to 500 feet in height; between these two regions a low plain stretches from north-west to south-east, its strata striking in the same direction.

The more elevated south-western part consists of ancient eruptive rocks which are described as porphyrites and volcanic agglomerates (Fig. 15). Stratified tuff rests upon these towards the north-east (T_1). The tuff is

[1] F. M. Stapff, Karte des unteren Khuisebthales, Peterm. Mittheil., 1887, pp. 202–214, map; A. Schenk, Ueber die geologischen Verhältnisse von Angra Pequeña, Zeitschr. deutsch. geol. Ges., 1885, XXXVII, pp. 534–536; for the south see also A. Moulle, Mémoire sur la géologie générale et sur les mines de diamants de l'Afrique du Sud, Ann. Mines, 1885, 8e sér., VII, pp. 193–348.

[2] J. C. Purves, Esquisse géologique de l'île d'Antigoa; Bull. Mus. R. Hist. nat. Belg., 1885, III, pp. 269–318, pl. xiv.

followed by the lower or marine siliceous limestone, which contains numerous remains of shells and in addition *Prionastraea diversiformis*, *Solenastraea taurinensis*, *Stylocoenia lobato-rotundata*, *Porites Collegniana*, which all occur in the Mediterranean deposits of Turin, and *Alveopora daedalea*, which lives at present in the Red sea, the Indian Ocean, and the Pacific (shown by the black band *a*, *a*, Fig. 15). This siliceous limestone is overlaid by sand and volcanic ejections (G); then follows upper siliceous limestone; it contains only fresh-water shells and silicified wood (the first

FIG. 15. *The Island of Antigua*, after Purves.

white band *b*, *b*, Fig. 15). Upon it rests another layer of tuff (T_2) and out of this a peak of trachydolerite projects. A strike fault, which traverses the whole island, repeats the outcrop of the beds *s*, *b*, and T_2. We have now crossed the mountains as well as the central plain, and have reached the foot of the hills which occupy the north-eastern part of the island. They consist of white or yellowish marl and white limestone; towards the south-west they end in a steep scarp; to the north-east the beds sink gradually beneath the sea, giving rise to numerous reefs (*c*). Here, according to Purves, the specimens of *Orbitoides Mantelli* from Antigua, described by Rupert Jones, were in all probability obtained; they indicate the horizon of the white Orbitoides limestone of Jamaica.

All the beds hitherto mentioned are very gently inclined to the north-east. In the most northerly part of the island they are covered by horizontal beds of marl containing a mixture of marine and terrestrial shells, nearly all of which belong to existing species (*d*). The lower marl beds are purely marine; in the upper beds the association with marine species of such genera as Melampus, Physa, and Planorbis, point to a muddy shore. A small exposure of basalt appears on the north coast.

This example shows how complicated the conditions are. The coralliferous deposits of the first Mediterranean stage (*a*, *a*) rest on older tuff. The eruptive activity persisted through all that part of the Tertiary period which is represented in the island, and the middle Tertiary Orbitoides limestone (*c*, *c*) sinks so gradually beneath the sea that its fragments, surrounded as they are by living coral reefs, might easily be mistaken themselves for modern coral reefs left dry by the sea.

The same deposits of the first Mediterranean stage which we have just mentioned probably also form the foundation of the Bahamas. The Orbitoides limestone also forms a large part of Florida and runs still further north in the valley of the Mississippi. In this table-land the gulf of Mexico is let down (I, p. 284) and forms the 'fore-sea,' a trough lying in front of the cordillera of the Antilles. The remains of the deep-sea fauna of the Pacific, living at present in the depths of the gulf of Mexico, and the intercalation of the lacustrine Grand Gulf Series above the marine Tertiary of the lower Mississippi, show that the separation of the Pacific from the Atlantic region must have taken place in comparatively recent times, under conditions so complicated and variable that we can at present form no clear conception of them.

Let us now turn our attention to the regions further south.

Marine deposits of Tertiary age extend far up the valley of the Orinoco.

The map of eastern Guayana, constructed by Vélain from the observations of Crevaux, shows a more or less east to west strike of the ancient rocks composing this region. The intercalated Palaeozoic beds which form the northern part of the basin of the Amazon follow the same direction, and the course of this coast from Cayenne to the mouth of the Amazon thus cuts directly across the strike. For almost the whole of this distance, however, a broad band of recent alluvial deposits appears to lie between the edge of the mountains and the sea[1].

Now the basin of the Amazon broadens out. From what we at present know of the structure of Brazil we must conclude that the contour of the continent also cuts across the strike of the rocks as far as cape Saint-Roque,

[1] C. Vélain, Esquisse géologique de la Guyane française et des bassins du Parou et du Yari, d'après les explorations du Dr. Crevaux; Bull. Soc. geogr. Paris, 1885, 7e sér., VI, pp. 453-495, map.

but from this promontory onwards the course of the coast, at least as far as Paraguay, is determined by that of the mountain ranges.

As regards this important region we may add to our previous remarks the following observations:—

Mr. Orville Derby has been good enough to call my attention to the way in which the direction of this coast is repeated not only in the course of the Parahyba but also in that of the Parana and the São Francisco. Indeed any map of Brazil will show that on leaving the watershed these two great rivers flow to the north-east and south-west on the same line parallel to the coast, and then both turn at a right angle to the sea. Their mouths are separated by 25 degrees of latitude. The mountain range, however, which is marked along the watershed on many maps does not exist.

The relation between these two rivers resembles that between the Indus and the Brahmaputra, which also flow in opposite directions along the same line of strike and then, deflected at right angles, leave the mountains by lateral valleys. The Rhine and Rhone afford a well-known example of precisely the same kind in the Alps; and in this connexion the Saint-Gotthard is only a secondary watershed within a longitudinal valley.

The structure of the mountain ranges which determine the direction of the coast and the course of these rivers is known in its main features chiefly from the descriptions of Orville A. Derby. These mountains are formed of folded Archaean rocks. They unite near the upper waters of the Rio Grande. The Serra do Mar runs from the south-west along the coast; the Serra da Mantiquira proceeds further to the north-east; towards the north-north-east, east of São Francisco, lies the Serra do Espinhaço, and another range, the Serra da Canastra already known to Eschwege, runs off to the north-west between the Rio Pardo and the Supucahy; it is continued in a manner not precisely determined towards Goyaz.

Against the west side of the folded Archaean region, extending towards the Parana, lies a tabular zone of horizontal beds, in which Devonian and Carboniferous fossils have been found. This zone lies at a height of 900–1,000 meters, and further north of 700–800 meters. Dykes of diabase break through it and project in ridges from its surface.

On the west of this tabular zone of Devonian and Carboniferous rises a scarped outcrop which runs from Uruguay to Minas Geraes; its eastern edge reaches a height of only about 1,000 meters on the Parana, and of 1,200 meters in Minas Geraes. This is the edge of another tabular zone, which consists of Permian or Trias with overlying sheets of melaphyre.

The eastern affluents of the Parana have cut deep furrows in the horizontal beds. The decomposition of the diabases and melaphyres produces the best soil for the coffee plantations.

On the São Francisco the structure is similar, but between the folded

Archaean chains and the region of horizontal strata a tract of folded Silurian appears [1].

Two elements must thus be distinguished in the south-east and east of Brazil, namely, the folded mountain ranges, which, as we have said, even include the Silurian on the São Francisco, and the flat-bedded table-lands, which begin with the Devonian and are very widely distributed towards the interior.

In these pre-Devonian mountain chains the older rocks lie towards the east, and the folding movement, as far as it has been at present recognized, was directed towards the interior. This observation is of great importance. *It assigns to the Serra do Mar in the continent of South America a position similar to that occupied in North America by the Appalachians.*

I believe, writes Mr. Orville Derby, that the comparison of the orographic system of Brazil with the Appalachians is based on a true homology, and that the chief difference lies in the age of the most important elevation, which in North America affects the whole Palaeozoic series, while the formation of the greater part, if not the whole, of the Brazilian was pre-Devonian.

It follows further that the coast mountains of Brazil occupy the same position with regard to the Andes as the Appalachians to the cordilleras of the west of North America, *and that in the whole breadth of both continents the tangential movement is directed from the Atlantic Ocean towards the Pacific.*

South of the La Plata we reach the region which lies within the virgation of the southern Andes. On the La Plata itself marine deposits of Tertiary age are present which extend far into the interior of the land. They are the commencement of that very varied series of horizontal Tertiary deposits, partly marine and partly continental, which, enclosed between the branches of the virgation, form the entire coast of Patagonia. They will be discussed in a later chapter.

As we have already learnt, the *Falkland islands* are a folded fragment of Palaeozoic sediments completely alien to the adjacent continent (I, p. 527). The reports of the German polar station in *South Georgia* show that the island is formed of folded clay slate [2].

[1] O. A. Derby, Contribuções para o estudio da geographia physica do Valle do Rio Grande, Bol. Soc. geogr. Rio de Janeiro, 1885, I, no. 4, 30 pp.; by the same, Geographia physica do Brazil, in d'Abreu e A. do Valle-Cabral, Brazil Geographico e Historico, vol. I, 1884, translated into English in the 'Rio News,' 5, 15, 24 December, 1884. A geological map of this region, by the same author, appears in K. F. van Delden Laërne, Brazilië en Java, Verslag over de Koffiecultuur in Amerika, Asië en Africa; Bijdr. tot de Taal-, Land- en Volkenkunde van Ned. Indië, 1885, IV, 6, pl. i; cf. also the present work, I, p. 510, note 2.

[2] E. Mosthaff und H. Will, Die Insel Süd-Georgien; Deutsche Geogr. Blätter, Bremen, 1884, VII, pp. 113–151, in particular p. 119, et seq.

Tristan da Cunha and *Diego Alvarez* (Gough) are of volcanic origin.

15. *General survey of the Atlantic coasts.* The numerous facts just discussed lead to the conclusion that a certain amount of symmetry exists between the two sides of the Ocean. In some cases comparison is impossible, in others a correspondence is striking, even if difficult to explain. I will now attempt a representation of the facts, taking each region in turn.

(*a*) To the north, in the middle of the Ocean, rises the wedge-shaped mass of *Greenland*; on each side lies the sea.

(*b*) The eastern boundary of this sea is formed in the first place by a range of ancient gneiss which strikes down from Magerö to the jagged peaks of the Lofoten, and is visible in the Hebrides further to the south-west.—The western boundary, in Davis strait and Baffin bay, consists likewise of a jagged gneiss range, which comes from the north and follows the coast towards cape Walter Bathurst, through Cumberland and Labrador up to the straits of Belle Isle.

(*c*) A folded range of pre-Devonian age, the *Caledonian mountains*, beginning probably in Norway, runs through the Shetlands and the Orkneys, Scotland, Wales, and a great part of Ireland. The Scotch horsts lie in its strike.—No corresponding range is known in America.

(*d*) On the east of the gneiss range and the Caledonian zone there follows in Europe the great *Baltic shield.* The folded Silurian beds of Norway appear to pass into the flat-lying Silurian of its western border. Archaean formations are exposed in the middle of the shield; the glint line completely surrounds it. The Varanger fjord, the lakes of Lapland, the gulf of Finland, lakes Ladoga and Onega and the gulf of Onega mark the edge of the shield. The shallow gulf of Bothnia lies upon it.

A similar structure is repeated in Canada. West of the gneiss range of the coast lies the great *Canadian shield.* It is surrounded by flat-lying Palaeozoic beds. The great lakes mark its southern boundary, which runs down through lakes Winnipeg and Athabasca, the Slave lake, Marten lake and Bear lake to Coronation gulf; then probably through Simpson strait and perhaps through Melville peninsula. Hudson bay, of no great depth, lies upon it.

In Europe, as in North America, there is a shield, a shallow sheet of water, a ring of glint lakes, and a flatly bedded Palaeozoic border.

(*e*) On the west coast of Ireland where the Caledonian mountains, striking to the south-west, disappear, the folded ranges of another chain arise, which proceed in an arc from the interior of the continent, striking first to west-north-west, and then to the west. It is folded to the north. This is the *Armorican arc.* It reaches the south-west coast of Ireland with a westerly direction; this coast, Cornwall and Devon, as well as the coasts of the north-west of France, owe their rocky shores to the way in

which these folds strike out to sea. This chain arose for the most part before the end of the Carboniferous period.

In the same way *Nova Scotia* and *Newfoundland* are detached from the contour of America and show us the folds of a great mountain range, which coming from the south-west assumes gradually a west to east direction. This range also is folded to the north like the Armorican arc; it also attained its chief development before the close of the Carboniferous period.

(*f*) In Europe there next follow the *Pyrenees*. It is impossible to discover a corresponding range in America.

(*g*) In Europe we now arrive at the basin of Asturias. There is nothing similar to be met with in America.

(*h*) We then come to the Mediterranean on the east side of the Ocean. It is closed in near Gibraltar by a chain folded towards the exterior and bent round in a sharp curve. This is the most westerly prolongation of the *Betic cordillera* and presents at the same time the only instance in which the outer margin of a folded range reaches the east coast of the Atlantic, without sinking beneath the Ocean in a rias coast.

On the west side of the Ocean, though further to the south, we see the Caribbean sea, girdled about by the *cordillera of the Antilles*, which also is folded towards the exterior and sharply curved round: this again is the only place on the western side where the outer border of a folded range reaches the coast without being faulted down as it strikes out to sea.

It is not possible to continue these comparisons further to the south.

Greenland lies symmetrically between two continents. The gneiss range of the Lofoten corresponds to that of Labrador; but the objection may be raised that in Europe the former is interrupted for a great distance and that the latter in America is little known. The Caledonian range is absent in America. The two shields correspond and the two pre-Permian rias coasts. The Pyrenees and the basin of Asturias are not represented in America; on the other hand there is a striking resemblance between the two Mediterraneans with their girdle of folds.

It may be observed that certain elements are represented in Europe twice over as it were; thus the Armorican rias coast is repeated by the Pyrenees and the basin of Asturias by the girdle of the Mediterranean. This duplication, however, arises from the repetition of the pre-Permian by the Tertiary ranges, the building and rebuilding of Europe revealed by the horsts.

The Caledonian folds do not come into question here; they are not known in North America, and in the northernmost part of Norway no Caledonian folds are interposed in the course of the horizontally stratified masses of the lake region as they extend to the west, up to the dislocation which separates them from the gneiss of the Lofoten.

Dingle bay on the west of Ireland, on the outer border of the Armorican arc, corresponds consequently to Belle Isle straits between Labrador and Newfoundland. Both lie approximately in the same geographical latitude. But thence to the south the homologous parts of Europe are much more closely crowded together than their Mexican equivalents, and thus the Mediterranean lies considerably further north than the Caribbean sea.

It is to the repeated reconstruction of Europe that the peculiar difficulties are due which have always confronted tectonic studies in this continent. Elsewhere the mountains are more uniform in structure, planned on broader and simpler lines. Even if in many cases we have not been able to follow the bordering faults all round the mountain fragments which we have represented as horsts, even if we prefer to assume that the Central Plateau and Brittany, for example, have been separated across Poitiers not by subsidence, but by erosion, yet this will not alter the result. From the lower Guadalquivir up to the neighbourhood of Brünn the younger folded ranges are faced by the walls of faults. What is there known as the sierra Morena is here called the Manharts-Gebirge, and the only question which remains is to what extent the fragments to the north of these walls are to be regarded as independent of one another. This question, however, is only of secondary importance, since within the mountain segments themselves mighty dislocations are present of the most various age, as for example the marginal fractures of the Scotch trough, the fault of Saint-Ingbert in the basin of the Saar and the Letten kluft near Przibram.

CHAPTER III

THE BORDERS OF THE PACIFIC OCEAN

New Zealand. Australia. New Caledonia. The sea of Banda, Borneo. Cochin-china, Tongking. The Philippines. Formosa and the Liu-Kiu islands. Japan. The Kuriles and Kamchatka. General survey of the island arcs. Eastern China. North-eastern Asia. The arc of the Aleutian islands. The west coast of America.

1. *New Zealand.* Since the brilliant description of this island group by F. von Hochstetter, our knowledge of its structure has been greatly increased by the contributions of Hutton and Julius von Haast and by the work of the Geological Survey under the direction of J. Hector. Space precludes more than a summary of the most important results achieved by these laborious investigations; I am fortunate, however, in having at my disposal, not only a large body of already published material and the general geological map by Hector, but also information afforded me in friendly communications by Herr von Haast, and a detailed manuscript sketch which I owe to the kindness of Captain Hutton.

The series of marine beds in New Zealand is very complete. The Silurian is represented by at least two series of fossiliferous strata, a lower group with Graptolites and an upper group with Trilobites; the Devonian is less distinct; the Carboniferous limestone contains *Spirifer bisulcatus*, *Productus brachythaerus*, and other characteristic species; above it lies the group distinguished by Glossopteris, but the marine Carboniferous beds, which in Australia overlie the coal with Glossopteris, are not recorded from New Zealand. The Trias is represented by the Wairoa beds with Pseudomonotis and Halobia. Then follow beds distinguished by Ammonites and Brachiopods, which are assigned to the Lias or lower Jurassic (Catlin's *River and Bastion Series*), and plant-bearing beds with *Macrotaeniopteris lata*, which are correlated by Hector with the Rájmahál series of India. This flora, corresponding approximately to the middle of the Gondwana series, is evidently the same as that which extends with such an astonishingly wide distribution through almost the whole of Eurasia; as regards its relations to the marine deposits of New Zealand, there is at present great dearth of information. Deposits with *Belemnites Australis* are rightly or wrongly regarded as representatives of the lower Cretaceous; then follow very fossiliferous sediments of the middle Cretaceous and a series of marine Tertiary formations. The sediments are accompanied

by various volcanic rocks, which begin in the Palaeozoic aera and, on North island, are still in process of extrusion.

Varied as is the succession of the strata, the structure and features of the land are no less so. In the south it forms a true Alpine region where several peaks rise above 3,000 meters; in the middle of North island lies one of the most remarkable volcanic areas in the world. The outlines of the islands, however, correspond only in part with the trend of the mountain folds; fracture and subsidence have had a large share in their formation.

Hochstetter had already suspected that Cook strait and Foveaux strait, which separate the three islands, were due to the subsidence of mountain blocks; he was also aware that the mountain chain which follows the east coast of North island from East cape to Wellington is continued on the other side of Cook strait between the east coast of South island and the river Awatere, and that this continuation lies to the east, outside the trend of the principal chain[1]. More recent investigations in the south, however, have revealed the remarkable fact that in the southern half of South island two directions of strike and folding encounter one another almost at right angles, and the knowledge we have acquired in other parts of the earth leads us to conclude that in this region *two independent unilateral chains meet in syntaxis.* One of these chains trends to the north-east, and its oldest rocks lie to the north-west and west; all the mountain fragments of North island belong to it. The second chain runs, so far as it is known, to the south-east, and its oldest rocks crop out on its south-west side; it includes the southern part of South island together with Stewart island. On the east coast near Dunedin it is broken off transversely across its whole breadth[2].

The chief structural features which are developed from this plan are as follows:—

A long narrow band of gneiss and ancient granite follows the west coast of the middle part of South island. It has been described by Herbert Cox[3]. Only a few Palaeozoic patches lie along the coast on the western flank of these ancient rocks; towards the east, on the other hand, they furnish the base of an extremely thick zone of slates, also Palaeozoic,

[1] F. von Hochstetter, Geologie von Neu-Seeland; Reise der österreichischen Fregatte Novara um die Erde, Geologischer Theil, I, 4to, Wien, 1864, p. xlvi, 2, et passim. Hochstetter's first impression of Cook strait was not that of simple fracture, but of a displacement of the islands in an opposite direction by a mighty lateral force; by the same, Lecture on the Geology of the Province of Nelson, New Zealand Government Gazette, Nelson, Oct. 22, 1859, p. 101.

[2] I refer the reader to the diagram of South island in Hutton's Sketch of the Geology of New Zealand; Quart. Journ. Geol. Soc., 1885, XLI, p. 195.

[3] S. H. Cox, Report on Westland District; Rep. Geol. Surv. New Zealand, 1874-1876, Wellington, 1877, pp. 63-93, map.

which form the highest summits of the New Zealand Alps. Here is situated mount Cook, which attains a height variously estimated at from 3,762 to 3,963 meters; great glaciers descend from this lofty range; a vivid and instructive picture of the region has been given by Von Lendenfeld[1]. Towards the east the range slopes down and is followed by a long synclinal

FIG. 16. *New Zealand.*

A, Archaean; *p*, crystalline schists and Palaeozoic; *trj*, Trias and Jurassic; *crt*, Cretaceous and Tertiary; dotted areas, volcanic regions, chiefly acid lavas and their associated tuffs; black, principal volcanos and basic lavas; white, recent alluvium.

of Mesozoic beds, till the Palaeozoic foundation again rises in an anticlinal; then comes a broad plain on the east which unites the border of the mountains with a block-like mountain mass projecting far out to sea. This is

[1] R. v. Lendenfeld, Der Tasman-Gletscher und seine Umgebung; Peterm. Mitth., Ergänzungsheft, Nr. 75, 1884, 80 pp., maps.

Banks peninsula. Haast, who has examined and described the whole of that part of the island just referred to, has shown that on the west side of this mass some ancient schists crop out, and associated with these quartz-bearing porphyry, but all the rest of the mass, which attains a height of 927 meters, rising from an area as large as the base of Aetna, consists of a number of closely crowded craters of various age, standing beside and above one another. Some of these reveal the same radial arrangement of the dykes as distinguishes mount Venda in the Euganean region (I, p. 146)[1].

The ancient rocks of the west strike to the north-east, and pass into elongated mountain cores; one of these reaches the sea on the west coast of Tasman bay. On North island neither gneiss nor granite is exposed.

Palaeozoic rocks also appear to the west of the crystalline schists of Tasman bay; but the principal zone, which runs from mount Cook to the north-east and includes many lofty peaks, reaches Cook strait, passing mount Franklin on the east side of Tasman bay; it then breaks up into a number of peninsulas, islands, and cliffs, and sinks beneath the sea between d'Urville island and Blenheim. To the east the principal Palaeozoic zone is followed by the Mesozoic synclinal, which still further east, beyond the river Awatere, is followed by Palaeozoic anticlinals; towards the east coast these in their turn are accompanied by a Mesozoic zone.

These anticlinals of Palaeozoic rocks lying east of the Awatere form the Kaikoura chains, which attain a height of over 8,000 feet; Hochstetter rightly recognized them as the continuation of the long Palaeozoic range of North island: this begins near Wellington, and as the Tararua chain, the Ruahine chain, or under other names attains in several places a height of over 5,000 feet; it finally reaches the north coast east of the bay of Plenty. A Mesozoic zone and subsidiary Palaeozoic chains border its east side from cape Palliser to cape Runaway, so that the course of this part of the coast corresponds with the actual strike of the beds.

The long and narrow Palaeozoic band running from Wellington to the north coast, which for brevity we will call the Ruahine chain, is the only continuous folded range of North island. Towards the west it is followed by the extensive volcanic region of lake Taupo with the gigantic volcanos Tongariro and Ruapehu. On the west side of the island another volcano, mount Egmont, emerges in a great circular outline from the sea. Tertiary and even more recent sediments form the north coast of Cook strait between this broad cone and the south end of the Ruahine range. To the north-west Palaeozoic rocks are known in many localities; up to the North cape, however, and beyond it, these are only the isolated fragments of the sunken range, between which recent volcanos appear in

[1] Julius v. Haast, Geology of the Provinces of Canterbury and Westland, 8vo, Christchurch, 1879, pp. 324–349.

many places, especially near Auckland. More recent sediments, tuffs, and lavas unite these fragments by a superficial covering, and so form the greater part of North island. The regular arc-like curve of the north-western shore is formed by littoral accumulations which run from one mountain fragment to another. The north-western coast, therefore, in no way represents the actual trend of the mountains. The south-east coast, interrupted by Hauke bay, alone corresponds with this direction.

The principal chains of South island disappear at Cook strait, and it is only a secondary chain which is continued across North island as the Ruahine range. We naturally look for the continuation of the principal chains of the south beneath the volcanic region of the north. 'Probably,' says Hutton, 'the ge-anticlinal of the South island runs through the centre of the North island from Wanganui to the bay of Plenty[1].' Hochstetter has already distinguished under the name of the Taupo mountains a series of recent volcanos running right through North island parallel to the Ruahine range and to the west of it. This zone, characterized by acid lavas, runs in a north-easterly direction from the mouth of the Wanganui on the coast of Cook strait to the island of Whakari (White island), an active volcano which rises from the bay of Plenty. Ruapehu (2,793 meters), Tongariro (2,582 meters), lake Taupo, Tauhara and Putanaki (mount Edgecumbe) lie on this line, which Hochstetter regarded as the boundary or margin of a downthrown area[2].

Let us return to South island.

The syntaxis does not take place at an acute angle, but in a fairly open curve. Possibly the form of syntaxis as projected on the map is determined by the degree to which denudation has advanced.

A Palaeozoic spur runs out from the region of mount Cook to the south-east, and approaches the mouth of the Waitaki on the east coast in a gentle curve. A second arc lies to the south of this river. Finally, the whole of the Palaeozoic zone, here very broad, swerves round near lake Wanaka, in west Otago, from south-west through south to south-east, and then ends by breaking off on the coast near Dunedin as we have already seen. On the south-east coast this zone extends to Molyneux bay, and is there followed on the south by a very remarkable Mesozoic zone, which includes the Hokanui mountains and is distinguished by a particularly rich succession of Jurassic beds, both marine and continental, as the observations of Cox and M'Kay have shown[3]. This zone takes part in the folding,

[1] Hutton, Sketch of the Geology of New Zealand, p. 197.

[2] F. von Hochstetter, Geologie von Neu-Seeland, p. 92 et seq.

[3] S. H. Cox, Report on the Geology of the Hokanui Ranges, Southland, Rep. Geol. Surv. New Zealand, 1877–1878, Wellington, 1878, pp. 25–48, map; Alexander M'Kay, Notes on the Sections and Collections of Fossils obtained in the Hokanui District, tom. cit., pp. 49–90; by the same, Mataura Plant-beds, Southland County, op. cit., 1879–1880,

strikes to the south-east, and finally almost due east. To the south and south-west it is again followed by slates, forming the north part of Stewart island, and then finally by gneiss.

The extreme south-west of South island from Milford sound onwards consists of gneiss; the coast is very steep and cut into by deep fjords; gneiss also forms the southern moiety of Stewart island.

The processes by which the mountains of New Zealand have been built up were distributed over an extremely long period of time. Folding movements occurred before the Mesozoic aera; the middle and upper Cretaceous in particular, distinguished here as in Europe by the presence of a dicotyledonous flora, lies in discordance in many places, but in several parts of South island post-Cretaceous folding is also known. The active volcanos, the numerous hot springs of North island, and the seismic phenomena show that the breaking up of the cordilleras cannot be regarded as yet at an end.

'Mountains with sharply jagged peaks,' writes Captain Hutton, 'are the exception in Switzerland, and the rule in New Zealand. Waterfalls are rare in New Zealand; a few occur up the deep fjords of the south-west coast, and some few small ones at the head of the valleys in the great ranges. Yet the Alps of New Zealand are quite as bold and steep as those of Switzerland; their ravines are even more numerous and deeper. The passes are deeper in New Zealand, the valleys much more terraced, and the mountains on the whole more extensively covered by loose débris than in Switzerland. This is certainly truer of Canterbury, Nelson, and Marlborough, than of Otago. The explanation lies in the fact that the Alps of New Zealand are *by far the older*. They have been exposed to the action of the weather, at least in part, since the Jurassic period, and many of the larger valleys were already excavated, almost to their existing depth, before the Oligocene period.'

The smaller islands which surround New Zealand in the south and south-east have a very varied structure. Such observations as exist upon them have been brought together by Meinicke and Hutton[1]. Since

pp. 39–48. In this work some remarkable observations are recorded on the passage of the stalk of Macrotaeniopteris through several beds of sand; this suggests that we may here have beds of aeolian origin. In the interior of the chain also the syntaxis does not take place at an acute angle, for at the northern half of the elbow-like bend of lake Wakatipu M'Kay observed a strike from north to south (District West and North of Lake Wakatipu, tom. cit., p. 118 et seq.), and the south-south-easterly direction occurs first on lake Te Anau, which lies on the boundary between ancient schist and gneiss (Cox, Report on the Geology of the Te Anau District, op. cit., 1877–1878, p. 110 et seq.).

[1] C. E. Meinicke, Die kleinen Inseln im Süden und Südosten von Neu-Seeland, Peterm. Mitth., 1872, XVIII, pp. 222–226; F. W. Hutton, On the origin of the Fauna and Flora of New Zealand, Ann. Mag. Nat. Hist., 1884, 5th ser., XIII, pp. 425–448, and 1885, 5th ser., XV, pp. 77–107; in particular in the latter part, p. 80 et seq.

nothing in the nature of a general view can be gained from these widely separated localities, the following brief account may suffice.

From the *Snares* islands Armstrong obtained basalt, decomposed quartz porphyry, and jasper. *Auckland* island, according to Hector, consists of granite, Tertiary sandstone, and volcanic rocks: this accords with the specimens collected by Armstrong. On *Macquarie* island, Scott found greenstone and amygdaloids with mesotype and analcime. *Campbell* island, according to Hector, presents blue slates and limestone which resemble the older Mesozoic rocks of New Zealand, as well as Cretaceous with flint, and volcanic rocks[1]. The *Antipodes* islands consist of dolerite and phonolite. *Bounty* island, according to Norman, appears to consist of granite. On *Chatham* island, according to Haast and Travers, mica-schists, Miocene limestone, and volcanic rocks occur[2].

2. *Australia.* An ancient folded range accompanies the whole of the eastern coast of the Australian continent. It rises in Tasmania in wild highlands covered with great lakes, projects from Bass strait in the form of numerous islands, and on the other side, in the south-east of Australia, attains its loftiest summit, over 7,000 feet in height[3]. It proceeds along the east coast, rises in lat. 17° 30′ S. to over 5,000 feet in the Bellenden Ker, and then decreases considerably in height. We shall find traces of it, however, up to the extreme north of York peninsula and across Torres strait.

This great folded range may be followed through 34½ degrees of latitude, but its southern end, at South cape in Tasmania, is defined by a fracture, and its northern end is not known. It bears no general name; following Clarke, who has done so much for our knowledge of Australia, we will speak of it as the *Australian cordillera.* This name, however, ceases to be applicable to some of the elements into which it breaks up, though these are closely connected among themselves. In the southernmost part of the continent the cordillera sends off a hilly range, which curves first in an arc and then runs from east to west through Victoria. Selwyn and others, however, showed long ago that even in this east to west ridge the foldings present the same north and south strike as on

[1] Filhol's statements as to the age of the limestone in Campbell island are unfortunately so contradictory that I must refrain from making use of them; H. Filhol, Mission de l'île Campbell: Constitution géologique de l'île, Compt. Rend., 1876, LXXXIV, pp. 202–205, and Rapports géologiques et zoologiques de l'île Campbell avec les terres australes avoisinantes, op. cit., 1882, XCIV, pp. 563–565.

[2] In the Tertiary deposits of Chatham island Hutton recognizes the Pareóra system of New Zealand; Quart. Journ. Geol. Soc., 1885, XLI, p. 209.

[3] R. v. Lendenfeld gives mount Townshend with a height of 7,256 feet as the highest point, whereas its neighbour mount Kosciusko or Mueller's peak (7,176 feet according to Neumayr) is usually so regarded; Lendenfeld, The Glacial Period in Australia, Proc. Linn. Soc. N.S.W., Sydney, 1886, X, p. 47.

the east coast, so that here the course of the range is perpendicular to its structure [1].

Broad plains succeed the cordillera on the west; then comes, north of the Darling river, a mountainous tract, formed by Barrier range and Grey range, which also runs north and south. This is again followed by lowland, and then we meet the much more important chains situated on the east, in part also on the west, of Spencer gulf, lake Torrens, and lake Eyre. To the west of these chains is a broad table-land which extends as far as the west coast of the continent.

The south-western part of this table-land is formed of granite and gneiss, with an undulating surface, and along the coast it breaks off in a long scarp. This scarp is known in the south as the *Darling range.* Gregory, in his laborious explorations, traced it for more than nine degrees of latitude, from cape Beaufort in Flinders bay up to the river Gascoyne. In the south it presents a steep face, 800 to 1,200 feet high for more than four degrees of latitude, while at a greater distance from the sea the table-land reaches a height of 1,400 to 2,000 feet. At the foot of the scarp lies a strip of flat land with rare extrusions of basalt, and in front of this again, in the extreme south, another gneiss zone running from cape Leeuwin to cape Naturaliste. Further to the north, from about lat. 31° S. a narrow gneiss zone again appears in front of the scarp; it recedes from the latter more and more to the north-north-west, including in this manner the coal-field on the river Irwin. The same zone of gneiss reappears between the river Greenough and Murchison. It is possible that it forms Edel land and the regions around Shark bay [2].

The section which Gregory has drawn from west to east in lat. 25° 15′ S. represents the table-land as consisting of gneiss and granite overlaid by metamorphic schists; while to the west of it lies a Palaeozoic series from which Carboniferous fossils have been obtained, and this is covered by Mesozoic beds with Ammonites and Trigonias. Since these observations, Huddlestone has shown that, according to the collections made by Forrest, a great zone of Carboniferous limestone may be recognized on the Kennedy range as far as lat. 24° S., which extends west of the ancient rocks towards the north: the Mesozoic fossils of western Australia have been examined by Moore and Neumayr. According to Neumayr's results only a part of the middle Jurassic, the zone of *Stephanoceras Humphriesianum*, can as yet be definitely shown to exist here or elsewhere in Australia. The zone, however, recalls in a truly astonishing manner the corresponding beds of

[1] A. R. C. Selwyn, Geology of the Colony of Victoria, in 'The Colony of Victoria in Australia, its Progress, Resources, &c.,' published for the International Exhibition in London, 1862, 8vo, Melbourne, 1861, p. 185.

[2] F. T. Gregory, On the Geology of a Part of Western Australia; Quart. Journ. Geol. Soc., 1861, XVII, pp. 475-483.

Europe. The general characters of all the species are similar, and some of them are identical; even the nature of the rock, which is a reddish-brown oolite, is the same. The beds overlying this zone have afforded a number of upper Cretaceous species which have been described by Moore [1].

We may consider the long face of the table-land to which the Darling range belongs as a fault scarp, and the Carboniferous and Mesozoic beds, which lie in front of it on the west, as downthrown zones. This is an interpretation which in many similar cases elsewhere has alone proved capable of explaining all the facts.

The surface of the table-land, as far as it is known, consists only of granite, gneiss, and ancient schists, and is widely covered with sandstone. The sandstone contains no fossils, and its beds occupy a very large part of the interior. We will call it with Daintree the *Desert sandstone*. Forrest, who penetrated into the interior from the west coast in lat. 29° S. nearly as far as long. 129° E., also encountered nothing but granite and sandstone.

The south coast of Australia is particularly characterized by the large part taken by marine Tertiary beds in its formation. Clarke has emphasized the remarkable fact that while marine Tertiary sediments occur with so great an extension on the south coast, yet so far not a trace of such deposits has been met with on the east coast in its course from cape Howe to cape York, or on that side of the Australian continent which is known in greatest detail [2].

All these Tertiary beds are horizontal; their upper limit lies only a few hundred feet above the sea; the fossils they contain show that they are of various age. The lower beds contain very few species known to occur in the existing seas. The Australian palaeontologists have attempted, in spite of Duncan's objections, to apply the European terms Eocene, Miocene, and Pliocene to the various subdivisions, according to the percentage of existing species they contain [3].

In the Great bight, in the St. Vincent gulf, and in the fluvial region of the Murray, these deposits penetrate far into the continent. Tate has given an instructive account of their mode of occurrence in the *Great bight*; to this I am indebted for the following account [4]:—

[1] W. H. Huddleston, Notes on a Collection of Fossils and of Rock-specimens from West Australia, North of the Gascoyne River, Quart. Journ. Geol. Soc., 1883, XXXIX, pp. 582–595, pl.; C. Moore, On Australian Mesozoic Geology and Palaeontology, op. cit., 1870, XXVI, pp. 226–263, pl.; M. Neumayr, Die geographische Verbreitung der Jura-formation, Denkschr. k. Akad. Wiss. Wien, 1885, L, p. 117 et seq.

[2] Rev. W. B. Clarke, Remarks on the Sedimentary Formations of New South Wales, illustrated by References to other Provinces of Australia, 4th ed., 8vo, Sydney, 1878, p. 7 et passim.

[3] A summary is given by J. E. Tenison Woods, Physical Structure and Geology of Australia; Proc. Linn. Soc. N.S.W., 1883, VII, p. 380 et seq.

[4] R. Tate, The Natural History of the Country around the Head of the Great Australian Bight; Trans. and Proc. and Rep. Phil. Soc., Adelaide, South Australia, for 1878–1879, 8vo, Adelaide, 1879, pp. 94–128, pl.

The great Tertiary plateau is framed round by granite, gneiss, and ancient schists. These rocks are seen in the west near Culver point (long. 124° 45′ E.), in the interior of the country near Boundary Dam (lat. 29° 20′ S., a little to the west of long. 129° E.), then in the east near Coldea waters (long. 131° 50′ 31″ E., lat. 30° 20′ S.), and near Pidinga (long. 32° 7′ 11″ E., lat. 30° 10′ 25″ S.). They reach the coast near Fowler's bay (between long. 132° and 133° E.). They also form the foundation of the whole of Eyre peninsula, which is surrounded only by a narrow border of recent marine sediment.

Within this outer frame stands the plateau which reaches the sea in a gentle curve between Culver point and Fowler's bay, thus forming the inner limit of the Great bight.

From Culver point for about a hundred miles to the north-east the southern edge of the plateau forms a wall descending vertically into the sea; then the edge recedes a little, a flat known as Roe's plains lies in front of it, and the cliff bears the name of Hampton range; at Wilson's bluff near Eucla (long. 129° E.) it once more reaches the sea, and from here to the head of the Great bight (long. 131° E.) it again forms a vertical, often indeed overhanging wall, which, bordered by no intervening flat land, plunges directly into the sea. This is the well-known *Bunda cliffs*. From the head of the Great bight up to Fowler's bay, sand dunes and recent marine deposits rest against the cliff, and in great part conceal it from sight.

The great tabular Tertiary mass, bounded in this fashion, is named by Tate the *Bunda plateau*; on the maps a part of it is known as the *Nullabor plain*.

The Bunda cliffs at their western end are 250 feet high, at the eastern only 155 feet. They reveal three groups of strata; at the top a bed of hard limestone, brown, grey, or reddish in colour, beneath this loose yellow Polyozoan limestone, and finally a white chalky rock, with strings of dark flint, which presents much resemblance to the white chalk of England. This lowest member has the greatest thickness. Near Eucla the upper limestone is 50 feet thick, the Polyzoan limestone 12 feet, and all the remainder is included in the lowest stage. All the members belong to the oldest division of the Australian Tertiary.

The upper limestone forms the entire surface of the Bunda plateau. It is an exposed sea floor. No tree, no water, no valley is anywhere to be seen. Caves run through the rock; red clay, residual from solution, covers the lower-lying places. It is a desert 'karst' land, and many a moving tale is told of the privations and sufferings, sometimes only ended by death, of travellers who have ventured upon this vast plain without sufficient provision against its dangers.

The Tertiary deposits which appear on the north side of Kangaroo

island in Aldinga bay, and about a great part of St. Vincent gulf, were regarded by Tate as the continuation of those of the Bunda plateau. They rest against older rocks which form a part of Yorke peninsula, and rise north of cape Jervis in long ranges running north and south. These ranges, hitherto unfortunately but little investigated, must now engage our attention [1].

The rocks which compose them are all of great age. The few fossils hitherto found belong to the lower divisions of the Silurian. In Eyre land no definite general strike can be made out. On Yorke peninsula the Silurian is known to occur. A long and uniform range commences at the northern end of St. Vincent gulf: this is *Flinders range*. The chain runs with slight curvature along the east side of lake Torrens up to its northern end. It attains a height of 3,000 feet. Burr, who long ago examined the country around mount Arden between Spencer gulf and lake Torrens, makes the strange assertion that crystalline rocks such as gneiss and mica-schists occur higher in the series than slates, limestone, and sandstone; Selwyn does not express any decided opinion on this point, and the relations of the beds cannot at present be regarded as established.

Mount Norwest, north of lake Torrens, forms the northern end, slightly deviating to the north-west, of a branch of Flinders range. Scoular encountered here ancient purple slates and projecting ridges of quartzite.

The mountains, of very inconsiderable height, slope to the east beneath a broad plain of clay, containing nodules in which Mesozoic fossils are found; this plain surrounds lake Eyre on its southern side, which abounds in springs. The impervious clay forms the bottom of the numerous salt lakes of this region, but it sometimes contains beds of sand in which drinkable water occurs. It follows the south-west side of lake Eyre; to the west of this great lake slate and quartzite again crop out with a steep dip and form *Denison range*. Here also a well-marked deflexion to the north-west occurs. Whether this range is to be regarded as an independent structure, or as the continuation of mount Norwest, is difficult to determine, owing to the nature of the country [2].

Let us now return to the sea.

Adelaide range is a meridional chain which comes next on the east. It begins at cape Jervis, sends off two little branches from its southern end to the south-west, and then trends northwards nearly up to lake Frome (lat. 31° S.); it runs parallel to Flinders range and its summits attain approximately the same height. Still further to the east lies another

[1] The best summary is given by Tate, Leading Physical Features of South Australia: Anniversary Address of the President to the Philosophical Society of Adelaide for 1878–1879, tom. cit., pp. xli–lxxi.

[2] Gavin Scoular, Sketch of the Geology of the South and West Parts of the Lake Eyre Basin; Trans. Proc. Roy. Soc. S. Austr., Adelaide, 1887, IX, pp. 39–54, map.

meridional chain formed of *Barrier* and *Grey ranges*. It presents ancient rocks which appear to be the same as those already met with. Here we are in the midst of a very extensive region of marine Cretaceous sediments which spread from Queensland to lake Eyre and probably far beyond it.

I do not propose to discuss the Tertiary deposits of the Murray river in detail; they are more recent than those of the Great bight and are referred to the Miocene. Tenison Woods gives 600 feet as the greatest height at which they occur. They also extend on the south coast into Bass strait, and even reach the southern part of north Gippsland. There also, according to Howitt, the greatest height they attain is 600 to 700 feet[1]. They do not occur beyond cape Howe.

We now reach the region of the Great cordillera. It is indeed only a continuation, on a larger scale, of the same system of parallel chains which we have just passed in review. The mass of the mountains is formed of granite and porphyry, crystalline schists, Silurian and Devonian rocks, all intensely folded, standing indeed as a rule nearly vertical. The strike does not deviate essentially from the meridional direction, except in the north, where it becomes north-north-west. The Carboniferous lies fairly flat, in any case much less folded than the rocks of the high mountains, and all the younger strata may be regarded as horizontal.

In the whole region of the cordillera a very remarkable gap in the series of marine sediments occurs above the marine Carboniferous and extends as far up as the Cretaceous. In the place of marine formations a diversified series of plant-bearing strata appear, among which some sandstone beds occur, believed to be of aeolian origin. The variety of the floras, already apparent from the earlier investigations of Feistmantel, has been brought into the clearest light by Tenison Woods. It is so great that we may hope with the progress of these studies to recognize most of the members of the Indian Gondwána series in the region of the Australian cordillera[2].

It is a remarkable fact, however, that the flora of the Gondwána series is preceded in Australia by a number of others which have the character of the Palaeozoic floras of Europe. The most important which in the present state of our knowledge can be distinguished in this region are as follows:—

(*a*) A Devonian flora with *Lepidodendron nothum*, which occurs in

[1] A. W. Howitt, Notes on the Physical Geography and Geology of North Gippsland, Victoria; Quart. Journ. Geol. Soc., 1879, XXXV, p. 40.

[2] Otto Feistmantel, Die paläozoische und mesozoische Flora des östlichen Australien, Paläontographica, Suppl. III, Lief. 3, 1878–1879; and J. E. Tenison Woods, On the fossil Flora of the Coal Deposits of Australia, Proc. Linn. Soc. N.S.W. for 1883, VIII, 1884, pp. 37–167, pl.

Thuringia in the upper strata of the Cypridina shales, that is to say in the upper part of the Devonian of Germany; it is also known in the Devonian of Canada. Carruthers was the first to point out this correspondence [1]. Species of the genera Cordaites, Sigillaria, Archaeopteris, and others, are recorded from the same horizon.

(*b*) A flora which corresponds with the European Culm. *Lepidodendron Veltheimianum* was recognized by Crepin many years ago among Australian fossils. *Calamites radiatus, Cyclostigma australe,* Feistmantel (which this author admits he can scarcely distinguish himself from the Irish *Cyclostigma Kiltorkense*), *Rhacopteris inaequilatera,* and others also occur [2].

(*c*) After the Culm flora the striking correspondence with the floras of the northern hemisphere is interrupted for a long period, and strata with *Glossopteris Browniana* rest upon the lower Carboniferous limestone; they afford evidence of a glacial period; in the morainic accumulations of this epoch gold has been found in places. These beds correspond with the Talchir deposits of India.

(*d*) Above the marine beds which overlie these glacial deposits—the last marine beds of the cordillera till the Cretaceous is reached—various plant-bearing deposits occur which in their lower part still afford Glossopteris; they include the chronological equivalents of the Trias and the Rhaetic. Whether the equivalents of the Permian are also to be placed here must remain for the present uncertain.

(*e*) An extensive and important series of strata characterized by the genera Thinnfeldia and Taeniopteris includes the Jerusalem beds of Tasmania and the Clarence beds of New South Wales; it is also well represented on the east coast of Queensland.

We shall return to this non-marine series later. The deposits immediately succeeding are much more recent; they are marine, and according to Neumayr's investigations correspond approximately to the Aptian stage of the Cretaceous system.

The inhospitable *highlands of Tasmania* are a fragment of the Australian cordillera. The greater part forms a table-land about 4,000 feet high, which is cut up by valleys. To the east it breaks off sharply along the coast. Strzelecki laid the foundation of our knowledge of the island; his results have been supplemented by later works [3]. The rocks are the

[1] W. Carruthers, Notes on Fossil Plants from Queensland, Australia; Quart. Journ. Geol. Soc., 1872, XXVIII, pp. 350–354, pl.

[2] Tenison Woods, A Fossil Plant-Formation in Central Queensland; Journ. Roy. Soc. N.S.W. for 1882, XVI, 1883, pp. 179–192, pl.

[3] P. E. de Strzelecki, Physical Description of New South Wales and Van Diemen's Land, 8vo, London, 1845; Tenison Woods, A Physical Description of the Island of Tasmania, Trans. Roy. Soc., Victoria, Melbourne, 1883, XIX, pp. 144–166. On the watershed between the river Tamar and Port Sorel river the strike diverges considerably

same as those composing the cordillera on the mainland of Australia, but eruptive greenstones belonging to the later part of the Mesozoic period occur here in greater profusion. Granite, ancient crystalline schists, and Silurian beds are exposed in steeply upturned zones with a north and south strike; the Carboniferous, of marine as well as extra-marine development, lies flat upon them; then follow more recent plant-bearing beds; the horizon with Thinnfeldia is also represented, and all these deposits are surmounted by sheets of greenstone, which form a large part of the surface of the table-land. Marine beds of the Mesozoic period are entirely absent; Tertiary marine deposits corresponding to those of the Great bight are known on the north coast at a trifling height above the sea. Tertiary basalts occur both in the north and south of the island.

The rocks of the cordillera, locally overlain by Tertiary beds, now form the islands of Bass strait, and if we follow their strike to the mainland we reach the *Australian Alps*, the highest part of the cordillera. R. von Lendenfeld has described their structure in detail. Although in the south-east of Australia the principal range of mountains bends through an arc into an east and west direction, yet the structure, as we have previously observed, does not correspond with this direction. It is evident from R. von Lendenfeld's description that the arc breaks up into a number of transverse chains running meridionally or converging slightly to the south; these show the true strike of the steeply upturned zones of granite, gneiss, and Silurian in this region. In the Bogong mountains there occurs in addition an extensive eruptive mass of a basic rock, probably of Devonian age.

The tectonic trend-lines are slightly convex towards the east and indicate folding from the west. This folding is older than the Carboniferous [1].

The mountains proceed with the same structure from the east of Victoria to New South Wales, running fairly parallel with the coast, which descends rapidly to a depth of more than 2,000 fathoms. The geological

from the meridian (N. 20°–30° W); Norman Taylor, Notes on the Geology of the West Tamar District, Tasmania, Trans. and Proc. Roy. Soc. Victoria, 1880, XVI, p. 156. Many observers mention faults in Tasmania. Harrison writes on the region between the Derwent and mount Wellington as follows: 'As a very homely illustration we may suppose a set of wooden cubes to be laid out upon a yielding foundation, say a sofa cushion, so that the surface of the whole represents a perfectly level superficies. Anon, and some disturbing force changes the horizontal plane of each cube into a gently sloping incline, and forms at every joint a diminutive escarpment. If we can only imagine that some molten substance, such as wax, has been forced through the various interstices from beneath, so that its overflow partially fills up the miniature valleys, we shall have a model representation of Hobart Town with its sandstones, dislocations, and eruptive rocks;" T. Harrison, Notes on the Geology of Hobart Town, Trans. Proc. Roy. Soc., Victoria, VI, 1865, p. 133.

[1] R. v. Lendenfeld, Forschungsreisen in den Australischen Alpen; Peterm. Mitth., Ergänzungsheft, Nr. 87, 1887, 37 pp., maps.

map of New South Wales by Clarke and Wilkinson shows that nearly meridional zones of granite and steeply folded Silurian, accompanied by a number of similar zones of Devonian and ancient porphyry, form the east coast nearly up to Bateman's bay in lat. 2° 35′ 40″ S.; from this point to the north, their eastern border, following approximately the meridian of long. 150° E., recedes further and further from the coast; north of Mudjgee on the watershed between the Hunter river and the Macquarie in about lat. 32° 10′ S., the whole cordillera, still directed north and south, disappears beneath flat-lying Carboniferous beds [1].

While the zone is covered in transgression by the Carboniferous, there crops out to the east of it, in nearly the same latitude, along the Manning river, on the north border of the same overlying Carboniferous, another great zone of granite and Silurian, also striking north and south, which very nearly coincides with the New England range and runs northwards to Queensland. The cordillera thus consists here of two folded ranges, which alternate with each other; both strike with the meridian. The range coming from the south lies between long. 148° and 150° E. and disappears before it has reached lat. 32° S.; the range running to the north begins in lat. 32° S. and its central part lies between long. 151° and 152° E. The Carboniferous formation surrounds the end of one and the beginning of the other range, and extends along the coast from lat. 35° 40′ S. to beyond Port Macquarie, i. e. to beyond lat. 31° 30′ S. More recent plant-bearing beds overlie it in the south.

In this intermediate region of horizontal beds Sydney is situated, and the most important coal-measures of the colony occur here; these are the Glossopteris beds. The river-basin of the Hunter belongs to this region.

Let us again turn our attention to that folded range which begins in lat. 32° S. with the New England range. Daintree's excellent description of Queensland well enables us to recognize its peculiar features [2]. In the north part of New South Wales this range consists of folded lower Palaeozoic beds through the midst of which rise high granite mountains. Towards the north the granite seems to disappear; Devonian beds form the greater part of the range and an extremely long band of Devonian forms the continuation of the mountainous zone, following the course of the coast with a gentle curvature up to Shoalwater bay, i. e. to beyond lat. 22° 30′ S. According to existing accounts this chain thus extends

[1] Geological Sketch-Map of New South Wales, compiled from the Original Map of the late Rev. W. B. Clarke by C. S. Wilkinson; contained in Ann. Rep. Dep. Mines, N.S.W., for 1880, 4to, Sydney, 1881. According to Clarke (Remarks, &c., p. 18) the tin-bearing granite of Queensland and New South Wales is of Devonian age, and consequently much younger than the other granite.

[2] R. Daintree, Notes on the Geology of Queensland, Quart. Journ. Geol. Soc., 1872, XXVIII, pp. 271–317, map; R. Etheridge, Description of the Palaeozoic and Mesozoic Fossils of Queensland, tom. cit., pp. 317–359, pl.

from the parallel of 32° S., through 9½ degrees of latitude, to the north. Its opposite slopes are formed of different sediments. On the east side towards the sea there lies an almost continuous zone of Mesozoic plant-bearing beds, which begins in lat. 30° S. in New South Wales and extends to beyond lat. 25° S.[1] This is the chief region of the Thinnfeldia beds, and, as we see, this important area of deposition lies outside that of the coal-measures. On the west side of the mountains, however, lies a long zone of Carboniferous deposits. It has afforded marine fossils of the Carboniferous limestone and plants of the Culm. The beds are thrown into very broad undulations. This zone extends from the head waters of the Hunter along the west side of the New England range, and Daintree has traced the great outliers running parallel to the coast which form its prolongation even as far as between lat. 21° and 20° S. These outliers of the extreme north are situated in a granite region to which we shall refer presently.

The cordillera slopes to the west, beneath the desert sandstone and the marine Cretaceous deposits. These form the soil of the deserts of the interior up to the gulf of Carpentaria and far away to the west, only interrupted here and there by ridges of granite or Palaeozoic sediments. At one locality, however, near Maryborough in lat. 25° 30′ S., a little outlier of marine Cretaceous appears on the east side of the range resting on the Mesozoic plant-bearing beds.

The chain which begins with the New England range, terminates as we have seen at Shoalwater bay: it consists here of folded Devonian. It forms the middle part of the Australian coast which projects furthest to the east. In its northern part a strike of N. 30° W., corresponding to the course of the coast, has been observed in places. On the west side of Broad sound a great ridge of granite rocks crops out to the west of this Devonian range. Just as the long anticlinals of a folded range replace each other alternately, so apparently do these several zones. On the southern part of this granite range lie the most northerly patches of the Carboniferous zone; some Devonian and Silurian accompany the range in the west towards the plain, but from lat. 22° S. to the north the whole coast, as far as it is known, is formed of granite rocks. In this region the mountains have lost considerably in height. The desert sandstone encroaches steadily upon them from the west.

Rattray has described the desert land around cape York. The granite mountains extend along the east coast to the north; cape Melville (lat. 14° 15′ S.), cape Direction (lat. 12° 50′ S.), then Weymouth cape, Fair cape, and others, consist of granite; the extremity of the peninsula is of

[1] The south part of the Clarence river is described by Stephens, Notes on the Geology of the Southern Portion of the Clarence River Basin; Proc. Linn. Soc. N.S.W. for 1883, VIII, 1884, pp. 519–531.

porphyry. The desert sandstone forms the subsoil far and wide; on the island of Albany it reaches the sea. A red deposit resembling laterite rests upon it over large areas[1].

The islands and reefs of Torres strait consist in no small part of granite, and form the continuation of the cordillera towards New Guinea.

According to the observations hitherto made, the folded ranges of the Australian continent are parts of a mountain system distinguished by common characters. They are all more or less meridional, or so arranged that with a slight deviation from the north and south direction, such as occurs for instance in north Queensland, they form as a whole an arc slightly convex to the east. They are older than the Carboniferous and in Queensland in particular older than the Culm. The chains rise both to east and west, but chiefly to the east of the line of depressions which is marked by lake Eyre, lake Torrens, and Spencer gulf. The first is Flinders range, the second Adelaide range, the third Barrier and Grey ranges, the direction of which is continued far in the north by McKinlay range; the last, according to Daintree, also consists of ancient rocks. There now follow, to the east, the members of the great cordillera, namely a chain which runs from Tasmania through the Australian Alps up to the Hunter river in lat. 32° S.; a second which replaces the first in lat. 32° S., east of the Hunter, and strikes parallel to the coast up to about lat. 22° 30′ S.; finally a third which follows and replaces the second on the west side of its northern end, then decreases in height and, directed to the north-north-west, extends beyond cape York through the islands of Torres straits to New Guinea.

The volcanic formations have not yet been mentioned, although they play no inconsiderable part in the structure of the cordillera. There is here no question of those older eruptive rocks which, within the folded Palaeozoic series and in unmistakable association with the auriferous deposits, have played such an important part in these countries, but we are concerned with the much more recent lavas of middle Tertiary or even later age. These are exclusively basic. On the higher parts of the cordillera and its slopes, from Tasmania through Victoria, New South Wales, and Queensland, many basaltic streams and sheets are visible, resting in places on leaf-bearing beds which cannot be older than the middle Tertiary. Daintree has shown that the desert sandstone of Queensland rests upon lavas of this kind. At the same time it must be borne in mind that this widely extended aeolian formation is older than the fauna of the great marsupials, such as Diprotodon and its contemporaries, which are met with in much more recent breccias and in the erosion valleys of the desert sandstone.

[1] A. Rattray, Notes on the Geology of the Cape York Peninsula, Australia; Quart. Journ. Geol. Soc., 1869, XXV, pp. 297–305.

In Queensland, somewhat north of lat. 21° S., on the other hand, a number of eruptive centres occur which are shown to be of recent age by the complete preservation of their ash cones; in some places their lavas have flowed over the desert sandstone. Similarly, volcanic formations, still bearing their ash cones, are met with in the south, as in that part of Victoria where the direction of the mountains lies transverse to the structure, or in other words where the elevations but not the folds are bent round towards the west. These volcanic formations, bearing all the external signs of a recent date, are continued through the south of Victoria to the west. The cone of mount Gambier is superposed on horizontal marine beds of Tertiary age; Woods has described it in detail[1]. The remains not only of great marsupials, but also of the dingo, have been found in or beneath the ashes of these volcanos.

Basic volcanic eruptions have thus taken place in the cordillera since the Miocene period, and in the north, as well as in Victoria, they have lasted up to a very recent period.

There is little to say of the deserts of the interior. All that enterprising travellers have seen or collected in these inhospitable regions is granite, which appears to crop out at the surface in a weathered condition over vast areas; ancient schists; some exposures of marine Mesozoic deposits; and a vast covering of desert sandstone. The doubts which have been raised as to the presence of marine Jurassic beds in the east of the country have already been mentioned; the same uncertainty affects all the finds hitherto made in the interior; the Cretaceous alone can be regarded as definitely identified. This certainly extends from the western slopes of the cordillera, or more exactly from the outlier on its east side near Maryborough in Queensland, to mount Stuart in Grey range, beyond this past lake Eyre, to the north-west nearly to the gulf of Carpentaria, and certainly much further still into the interior.

The explorers who have entered the country from the north-west coast have also encountered only granite and desert sandstone, or possibly basalt as well, e.g. on the Victoria river. True Jurassic fossils are not obtained until we reach the Glenelg river between lat. 15° and 16° S.; this was the locality assigned to the specimens sent to Europe which Neumayr described; they show a striking correspondence with the species collected by Gregory and his successors in the more southerly parts of the west coast[2]. Similar deposits have as yet nowhere been met with in the centre

[1] J. E. Woods, Geological Observations in South Australia, 8vo, London, 1862, p. 224 et seq.

[2] Neumayr, op. cit., p. 140 et seq. Depuch island, long. 117° 44′ E., lat. 20° 37′ S., is said to be a great accumulation of blocks of greenstone rising 514 feet high above the flat coral reef of the neighbourhood; Wickham, Note on Depuch Island, Journ. Geogr. Soc., 1842, XII, pp. 79–83.

or east of Australia, and we must for the present consider these remarkable sediments, which recall so strongly the Jurassic deposits of Europe, as confined to the west of the table-land.

Let us now cross to the other side of the Pacific Ocean, within the same parallels of latitude, keeping in mind the results we have obtained in Australia and New Zealand.

On the western border of the Gran Chaco rise a number of lofty narrow chains composed of ancient rocks and running north and south: the dip of the beds is very steep. The most easterly of these, near the town of Cordóba, as for instance the sierra Ischilin, sierra de Cordoba and sierra Cerezuela, consist of granite, gneiss, and Archaean schists. Further north the sierra de Aconquija, formed of granite and gneiss, and a large number of narrow parallel ranges composed of Cambrian and Silurian beds continue this system of meridional sierras as far as Bolivia (I, p. 512). Further to the west the series of marine formations is completed by the addition of mighty Mesozoic deposits. Recently, Mojsisovics has shown that the marine Trias also occurs in the northern part of the Andes, as proved by the specimens found by Reiss and Strubel in Peru, and by Lindig in Chaparal [1].

With the completion of the Mesozoic series we reach the great mountains. Beyond them, there lies towards the west the deep valley of Chili, then the singular Coast cordillera, and last the Ocean.

Now let us cross Australia, but instead of from east to west we will take an opposite course and travel from west to east.

In place of the Gran Chaco or the Pampas, there lie before us the deserts of Western Australia; instead of the lagoons of the western border, the sheets of water which extend from Spencer gulf to lake Eyre; instead of the meridional sierras of Cordoba with their ancient rocks, we have Flinders range, Adelaide range, Barrier and Grey ranges; and the place of the other parallel chains is taken by the alternating members of the Australian cordillera. For a long distance the further extension of the continent is now concealed by the sea, but beyond it, in New Zealand, the Mesozoic series is completed, the marine Trias is represented together with several members of the Jurassic system, and with this completion of the series we reach the great ranges and at the same time a region of much more recent folding [2].

Just as the Argentine sierras on the border of the great plain cannot be separated from the principal range of the Andes, but constitute with it

[1] E. von Mojsisovics, Arktische Triasfaunen; Mém. Acad. Imp. Sci. Saint-Pétersb., 1886, 7e sér., XXXIII, p. 151.

[2] On the greater completeness of the series in New Zealand, see in particular Hector, The Geological Formations of New Zealand compared with those of Australia; Journ. Roy. Soc. N.S.W. for 1879, XIII, 1880, pp. 66, 67.

a single mountain system constructed on a common plan, so all the chains from Flinders range to the Australian cordillera, including the longer of the two syntactic mountain segments of New Zealand, must be equally regarded as parts of a single system similarly constructed on a common plan.

In this connexion we may recall the remarkable distribution of the marine Tertiary beds which border the south coast of Australia, enter into the transverse subsidence of Bass strait, and even reach the southern part of North Gippsland, but are entirely absent on the whole east coast of the mainland, as well as on the east coast of Tasmania, which is bounded abruptly by steep cliffs. Clarke consequently has been led to conjecture that the continuation of the Australian continent towards the east is cut off by a recent subsidence [1].

In confirmation of this hypothesis it may be pointed out that on Lord Howe island, between Australia and New Zealand, great bones of terrestrial animals have been found which are ascribed to the gigantic lacertilian forms Megalania and Notiosaurus. On the Australian mainland these genera were contemporaries of Diprotodon and other great marsupials, and thus lived after the deposition of the desert sandstone, or in very recent times. The existing area of Lord Howe island could not possibly have supported such large animals [2].

3. *New Caledonia.* Many years ago distinguished observers, such as Dana and Clarke, had been led to regard New Caledonia as the continuation of New Zealand; the connexion was said to be indicated by the strike of the north-western peninsula of New Zealand, and by Norfolk island. We know now that the direction of the peninsula does not correspond with the principal strike of New Zealand. There are certainly, however, some features in New Caledonia which reveal a particular resemblance with New Zealand.

Garnier and Heurteau have published detailed reports on the structure of this great island: its fossils have been described by Deslongchamps and P. Fischer [3]. The structure is as follows:—

On the south-west coast, and especially in the southern half of the

[1] Clarke, Remarks on the Sedimentary Formations of New South Wales, illustrated by References to other Provinces of Australasia, 4th ed., 8vo, Sydney, 1878, p. 7.

[2] R. D. Fitzgerald, Proc. Linn. Soc. N.S.W. for 1884, IX, 1885, p. 1206.

[3] Garnier, Essai sur la géologie et les ressources minérales de la Nouvelle-Calédonie, Ann. Mines, Paris, 1867, 6e sér., XII, p. 1, map; E. Heurteau, Rapport à M. le Ministre de la Marine et des Colonies sur la constitution géologique et les richesses minérales de la Nouvelle-Calédonie, op. cit., 1876, 7e sér., IX, pp. 232–454, map; for the fossils, E. Deslongchamps, Documents sur la géologie de la Nouvelle-Calédonie, Bull. Soc.Linn. Norm., 1864, VIII, pp. 332–378; P. Fischer, Notes sur les roches fossilifères de l'Archipel Calédonien, Bull. Soc. géol. de Fr., 1867, 2e sér., XXIV, p. 457, and F. Teller in E. Mojsisovics, Arktische Triasfaunen, Mém. Acad. Imp. Sci. Saint-Pétersb., 1886, 7e sér., XXXIII, p. 111 et seq.

island, melaphyre and associated tuffs appear in several places. These are followed on the east by an altered rock in which *Spirigera Wreyi* of the New Zealand Trias has been found. This is overlaid by Trias shales with *Pseudomonotis Richmondiana* and *Mytilus problematicus*, that is by the equivalent of the middle Trias of New Zealand. These deposits are known in the islands of Ducos and Hugon. The Trias zone is followed by a much longer narrow zone striking parallel to the coast and formed of a series of coal-bearing beds. These beds are known on the coast for a considerable distance to the north-west and consist chiefly of sandstone and conglomerate; some of the marine fossils found in them have been identified with species of the European Lias; the coal is supposed to be Rhaetic or Lias. The zone which follows the coal-bearing beds is by far the most important and occupies the greater part of the island; it is an enormous band of serpentine and green schists accompanied by dykes of euphotide, which is distinguished by its richness in chromite and nickel. This band of serpentine forms the Île des Pins and the southernmost part of New Caledonia, then the coasts on the north-east side up to Uailu, that is for half the length of the island, and on the south-west side up to Mont Dore. It then gives place on this side to the sedimentary zones already mentioned, and reaches the south-west coast further to the north; finally, striking right across the middle of the island, it reaches the most northerly point of New Caledonia and is even continued beyond it into the island of Paaba. This band of serpentine, striking from the Île des Pins to Paaba, rising in many isolated bosses, black, barren, and rocky, is frequently covered by dark red clay resulting from its disintegration. It often occupies the whole breadth of the island and is characteristic of New Caledonia.

All the rocks hitherto mentioned strike to the north-west in accordance with the direction of the island. This renders it all the more strange that in the northern part of New Caledonia there are other and older rocks which all strike in quite another direction. Heurteau describes them as a zone of mica-schists bordered on both sides by slates. The mica-schists form the fairly large mountain ridge which separates the river Diahot from the east coast; this ridge is directed to the north-west like the band of serpentine and the length of the island itself, but the mica-schists according to Heurteau's explicit statement strike across this ridge to the north-east. The slates extend to the south nearly as far as Uailu, from which point onwards, as we have already mentioned, the coast is formed of serpentine down to the southern end of New Caledonia. Crystalline limestone is interstratified with the slate zones on each side.

Heurteau's description of the valley of the Diahot shows that the strike of this ancient schist is actually N. 20° E. to N. 55° E.; it is solely at the north end of the island that the strike of the northern slate zone bends more and more into the general strike to the north-west.

Thus we recognize in New Caledonia two groups of rocks which strike in different directions. The first, occupying much the more extensive area, is directed to the north-west like the island itself, and consists of a zone of melaphyre and tuff, of Trias, Mesozoic coal-measures, and the great band of serpentine. The second group strikes to the north-east, is known only in the north, and consists of mica-schists and slate. The first group is a fragment of a mountain complex displaying parallel zones; as to its precise relations to the second group it is not possible at present to form any opinion.

The age of the great serpentine band is not known. Such a vast mass of serpentine has never yet been encountered at any other point on the whole west coast of the Pacific Ocean. Its position would seem to assign it to the outer zones of a great mountain range, like the serpentines which are known at so many points in the flysch: Heurteau, on account of the presence of nickel and cinnabar in both cases, has compared it to the serpentine of New Almada in the coast chain of California [1]. The more significant is the fact that fossils, which he regards as upper Cretaceous, have recently been described by Ratte from the interior of New California [2].

Recent volcanic rocks have nowhere been observed in the island.

I do not propose to refer in this place to the coral formations which surround New Caledonia, nor to the important calcareous deposits which form the parallel series of the Loyalty islands. These will be discussed in a later chapter. It is important, however, in view of later descriptions, to mention the fact that Tenison Woods has described marine Tertiary fossils from Viti Levu. The species are extinct, but still of tropical character [3].

There is an extreme dearth of information as regards the islands which follow towards the north-west—so far as they do not consist of coral reefs or more recent volcanic formations—and only their general direction permits us to form any conjecture as to their structural relations.

Only isolated specimens have been described from *New Britain* and *New Ireland*. As regards New Ireland, Schleinitz informs us that at Carteret and Sulphur harbour the mountains consist of limestone, but rolled pebbles show that granite, porphyry, hornblende, and sandstone may occur in the interior of the island. This agrees with Liversidge's account, who mentions besides porphyry and diorite, some grey limestone probably ancient, from a mountain 2,500 feet high, also somewhat ancient volcanic ashes, red jasper, sandstone, epidote, and amygdaloidal lavas. From New Britain various volcanic rocks and white limestone are recorded [4].

[1] Heurteau, op. cit., p. 399.

[2] Ratte, Proc. Linn. Soc. N.S.W., 1884, IX, p. 681. The genera quoted are Rostellaria, Fusus, Pleurotomaria (?), Belemnites, Nautilus.

[3] J. E. Tenison Woods, On some Fossils from Levuka, Viti; Proc. Linn. Soc. N.S.W., 1879, IV, pp. 358, 359.

[4] Von Schleinitz, Annal. d. Hydrographie, 1876, IV, p. 365; A. Liversidge, Rocks from New Britain and New Ireland, Journ. Roy. Soc. N.S.W. for 1882, XVI, pp. 47–51.

4. *The Sea of Banda, Borneo.* As we approach *New Guinea* we perceive the importance of the Tertiary formation in the archipelago of Sundu. We have already seen that the marine Tertiary sediments on the south coast of Australia are widely distributed in the Great bight, and that they enter Bass strait, but that the whole east coast of Australia and Tasmania up to Torres strait has never yet furnished any trace of marine Tertiary beds. In Hall sound, New Guinea, Maclay collected marine Tertiary shells, but Tenison Woods maintains that these are entirely different from those of the Tertiary deposits of South Australia [1]. According to Martin's descriptions a large part of the north-western coasts of New Guinea is formed of Tertiary limestone, chiefly distinguished by Orbitoides and Lithothamnia, and probably of early Miocene age: it ends in cliffs 200 to 300 meters high. This limestone likewise forms the little island of *Koor* in the south-west, and several of the adjacent larger islands, as well as the little island of *Sowek* in the north of Geelvink bay. On the island of *Lakahia*, opposite Merkus-Ort, sandstone with coal-beds is said to occur [2].

The snow-covered mountains in the interior of New Guinea are wholly unknown.

The Malay arc, which runs from Burma through Malacca, the Andamans and Nicobars, Sumatra and Java, to beyond Flores (I, p. 458), is difficult to follow, since our knowledge of the eastern parts of this long series of islands is very slight; it is, however, quite apparent that Sandalwood island and Timor lie outside the arc.

Very little is known about *Sandalwood island*. *Timor* differs considerably from the descriptions we possess of the islands lying within the arc. Since Beyrich first pointed out the presence of Carboniferous limestone on Timor, numerous investigators, Martin and Wichmann in particular, have published accounts of the rocks of this island. Ancient schists, tonalite, diorite and serpentine are present; the Carboniferous limestone is widely distributed; the occurrence of Trias has not been placed beyond doubt; the Tertiary deposits occupy a large area, and appear, as on Java, to rise to a height of several thousand feet in the interior of the island [3].

[1] C. S. Wilkinson, Notes on a Collection of Geological Specimens collected by W. Macleay, Esq., from the Coasts of New Guinea, Cape York, and neighbouring Islands, in Clarke, Remarks on the Sedimentary Formations of New South Wales, 4th ed., pp. 97, 98; further, J. E. Tenison Woods, On a Tertiary Formation at New Guinea, Proc. Linn. Soc. N.S.W., 1877, II, pp. 125–128 and 267, 268; further, by the same, Physical Structure and Geology of Australia, Proc. Linn. Soc. N.S.W., 1883, VII, p. 381.

[2] K. Martin, Eine Tertiärformation von Neu-Guinea und benachbarten Inseln, nach Sammlungen von Macklot und von Rosenberg's, Sammlungen des geologischen Reichs-Museums in Leiden, edited by K. Martin and A. Wichmann; Beiträge zur Geologie Ost-Asiens und Australiens, 1881–1883, 1. Ser., pp. 65–83.

[3] E. Beyrich, Ueber eine Kohlenkalk-Fauna auf Timor, Abh. Akad. Berlin, 1864, p. 61; K. Martin, Die versteinerungsführenden Sedimente Timors, nach Sammlungen von

Timor does not follow the direction of the great arc and its relations with the latter are not known. Let us now turn to the eastern end of the arc.

It is to my mind a very instructive fact that steep folds occur, as Verbeek has shown, in the Tertiary beds which lie at the foot of the volcanos in the residency of Cheribon in Java[1]. The continuation of the mica-schists of Java has been discovered in Madura, overlain, in this case as in that, by the marine Tertiary sediments. The line of volcanos is the only indication of the continuation of the arc through Bali, Sumbawa and Flores. Tertiary formations, as in Java and Madura, play a prominent part in the structure of these islands. The borders of the *Banda sea* have been described by Riedel. From his accounts we gain the most important fact that the islands of Romang, Damma, Teun, Nila and Serua form a long and connected chain of still active volcanos; as their further continuation we must probably regard the volcanic islands of Tuur, the most southerly of the Watubela group (south of the Gorong archipelago); its last eruption took place in the year 1659. These six volcanic islands lie exactly on the prolongation of the great zone of volcanos which curves down from Java, and they carry the arc into the immediate neighbourhood of New Guinea. The fact is all the more remarkable since outside the arc volcanic phenomena are only known at one point, that is on the east side of the island of Moa.

A series of middle Tertiary beds, consisting of sandstone, marl, or limestone, forms a great part of the islands lying in front of the volcanic chain. Leti and Moa are formed of this series, while the next island, Lakor, is a recent coral formation. The Luang-Sermatta group is also middle Tertiary, as well as the Babar group; from the latter, however, Mesozoic limestone said to be Jurassic is also mentioned. The Tanembar or Timorlao group consists almost exclusively of low-lying coral limestone, but in the south-eastern part of Jamdena, the largest island of the group, late Tertiary land is visible. In the Kei group the great island Nuhujuut is middle Tertiary; it rises towards the north to a height of 400–500 meters. The principal group of Aaru is a recent limestone plateau traversed by salt-water channels, 25 to 800 meters in breadth, which cross the island obliquely from coast to coast; in the south-east recent Tertiary land rises to a height of 50 meters[2]. It is clear from Martin's accounts that these Tertiary deposits are a continuation of those of New Guinea.

Reinwardt, Macklot und Schneider, Samml. geol. Reichsmus. in Leiden, 1881–1883, I, pp. 1–64, plate; A. Wichmann, Gesteine von Timor, op. cit., 1882, II, pp. 1–72, plate.

[1] R. D. M. Verbeek, Over de dikte der tertiaire afzettingen op Java; Verh. Akad. Amsterdam, 1883, XXIII, D, 11 pp., plate.

[2] J. G. F. Riedel, De sluik- en kroesharige rassen tusschen Selebes en Papua, 8vo, 's Gravenhage, 1886, maps. A map of Aaru in Verh. Gesellsch. f. Erdk. Berlin, 1885, XII, pl. i.

The two islands lying north-east of Timor, Eetar (or Weetar) and Keisar (1,200 meters high), each consist of ancient rocks with others which are apparently of Mesozoic age. In like manner, ancient rocks, said to be associated in places with Palaeozoic or Mesozoic limestone, form the high chain which extends from Buru (2,500 meters) past Ceram (also rising to 2,500 meters) to the Seranglas and Gorong archipelago. Middle Tertiary beds accompany this range, and form the island of Amboina. As on the Irawadi, the Nicobars, Sumatra, and Java, so now on the east coast of Ceram also, we meet with springs of petroleum [1].

The middle Tertiary series, distinguished in some of its members by coal beds, or by Nummulites, Orbitoides, peculiar Lithothamnia and the genus Cycloclypeus, is assigned by Verbeek to the Eocene in part, but is regarded by Martin as Miocene. Martin has found Tertiary limestone in Amboina, Buton, and Madura, and notably in Borneo, where it is widely distributed [2].

It cannot be denied that the volcanic chain which extends from Romang to Tuur presents a close resemblance to the volcanic arc on the inner side of the Lesser Antilles. The Tertiary islands and the recent limestone plateaux similarly correspond to the succeeding outer arc. The Banda sea would thus appear to be homologous with the Caribbean; and the Arafura sea, lying on the foreland, with the gulf of Mexico or the adjacent part of the Atlantic Ocean.

Although Mesozoic or Palaeozoic sediments are frequently mentioned as occurring in this region, yet as far as my information extends no organic remains, older than the Tertiary period, have hitherto been met with except in *Borneo*.

We possess a geological map of this great island, constructed by *Schwaner* and *Gaffron* in the years 1843–1848; it comprises the southern

[1] Riedel, op. cit., p. 86. On the petroleum of the east coast of Sumatra see Everwijn, Jaarb. Mijnw. Ned. O. Ind., V, p. 186; in North Sumatra, op. cit., IV, *a*, pp. 15–33 and 188; in Soerabaja, op. cit., IV, *b*, p. 118 et passim.

[2] K. Martin, Die wichtigsten Daten unserer geologischen Kenntniss vom niederländisch-ostindischen Archipel, Bijdr. tot de Taal-, Land- en Volkenkunde van Ned. Indië; uitgeg. vanw. het kon. Inst., &c., ter Gelegenh. van het VI. internat. Congress d. Orientalist. te Leiden, 8vo, 's Gravenhage, 1883, pp. 17–34; cf. also D. Schneider, Geologische Uebersicht über den holländisch-ostindischen Archipel, Jahrb. k. k. geol. Reichsanst., 1876, XXVI, pp. 113–134, maps. For Tertiary formations see in particular K. Martin, Neue Fundpunkte von Tertiär-Gesteinen im indischen Archipel, nach Sammlungen von Horner, Korthals, Macklot, Müller und Reinwardt, Samml. geol. Reichsmus. in Leiden, I, pp. 131–179; also A. Böhm, Ueber einige tertiäre Fossilien von der Insel Madura, Denkschr. k. k. Akad. Wiss. Wien, 1882, XLV, p. 359; on the disputed question as to the age of these deposits I must refer the reader to Verbeek, Boettger, Geyler, and C. von Fritsch, Die Eocänformation von Borneo und ihre Versteinerungen, Palaeontographica, 1875, Suppl. III, Heft 1, and Verbeek, Boettger, and K. von Fritsch, Die Tertiärformation von Sumatra und ihre Thierreste, op. cit., 1880, Suppl. III, Heft 8–11.

area and extends a little beyond the equator; there are also a series of detailed descriptions by Dutch mining engineers and an instructive general account of the whole by K. Martin [1].

The first explorers, Horner and Schwaner, had already recognized that in the interior of Borneo mountains exist formed of granite, serpentine, crystalline schist and other ancient rocks, which strike in a similar direction to the hill-ranges of Celebes and Halmahera; the hollows between them are, however, filled with Tertiary sediments. Martin shows how Pechel and Wallace had independently of each other perceived this curious homology of the three adjacent islands which yet finds so little expression in the outlines of Borneo [2].

Besides this Tertiary transgression, Verbeek has recently made known in Borneo fossiliferous marine deposits of the Cretaceous period, occurring on the Seterocang, a tributary of the river Kapoea which flows down to the west coast. Amongst the specimens collected by van Schelle, Geinitz has recognized some fossils so closely related to *Vola quadricostata*, *Trigonia limbata*, *Goniomya designata*, *Hemiaster sublacunosus* and *Hemiaster plebeius*, as well as other upper Cretaceous species, that he correlated the deposit with the upper Senonian [3].

Tenison Woods asserts that the coalfields of the west are contemporaneous, in part at least, with the Newcastle beds of Australia; with regard to Labuan this is merely a conjecture; the coal district of Sarawak has afforded *Phyllotheca australis* and *Vertebraria* sp., that is to say species characteristic of these Australian deposits [4].

Finally, marine fossils, either Devonian or Carboniferous, are also present; van Schelle mentions traces of them in the western residency and Tenison Woods quotes Fenestella and Stenopora from a limestone in the north [5].

5. *Cochin-china, Tongking.* In recent times our knowledge of the

[1] K. Martin, von Gaffron's geologische Karte von Süd-Borneo, Samml. geol. Reichsmus. in Leiden, I, pp. 179–193, map; also op. cit., p. 132 et seq.

[2] T. Posewitz' account of the case is perhaps too uncompromising, Unsere geologischen Kenntnisse von Borneo; Jahrb. k. ung. geol. Anst., 1882, VI, pp. 135–162, map.

[3] R. D. M. Verbeek, Over het voorkomen van gesteenten der krijtformatie in de residentie Westerafdeeling van Borneo; Versl. en Meded. K. Akad. Wet. Amsterdam, Afd. Natuurk., 1884, XIX, 2. reeks, med. pp. 39–43. Martin regards these deposits as a tropical modification of a Tertiary formation, but no member so far known among the Tertiary deposits of Java and Sumatra appears to be so rich in species usually supposed to be Cretaceous types.

[4] Tenison Woods, The Borneo Coalfields, Nature, April 23, 1885, pp. 583, 584; cf. also J. Motley, On the Geology of Labuan, Quart. Journ. Geol. Soc., 1853, IX, pp. 54–57.

[5] Schelle, Bericht in Peterm. Mitth., 1885, p. 320; Tenison Woods, The Geology of Malaysia, South China, &c., Nature, Jan. 7, 1886, p. 232. Hart Everett mentions crinoidal limestone from north-east and north-west Borneo, but without any closer indication of age; Report on the Exploration of the Caves of Borneo, Proc. Roy. Soc., 1880, XXX, pp. 310–321.

mainland of Further India has been largely extended by the labours of French geologists. The bold expeditions of Garnier have been followed by the investigations of Ratte and Petiton in lower Cochin-china and Cambodia, of E. Fuchs on the coast of Annam and in Tongking, and of Jourdy on the east of Tongking[1]. While many questions must still remain open, sufficient is ascertained to furnish the following account.

As in Borneo, recent eruptive rocks are very feebly represented; isolated occurrences of such rocks surround indeed the south and east coasts of Further India, but on the mainland itself they are known only at a single locality, quite close to the south coast. A boss of basalt occurs at this place, which is situated south of Bien-Hoa. The Tigre, a little island on the east coast (N. of lat. 70° N.), consists of trachyte; trachyte is also known from Pulo Condore and Pulo Wai in the east and west of the southern extremity of Cochin-china.

A part of Pulo Condore, however, consists of granulite, and this is the forerunner of numerous protrusions of this rock which rise near cape Saint-Jacques and in the neighbourhood of Baria. They are accompanied by diorite and are associated towards the north with considerable masses of ancient schistose rocks. These isolated exposures of ancient rocks, extending towards cape Saint-Jacques, must be regarded together with Pulo Condore as the southern extremity of the long range of hills which, starting from the granitic table-land of Laos, descends along the east coast of Annam.

We will first describe somewhat in detail the delta of the Mekong.

The granulite hills of Baria are continued to the north-west to Bien-Hoâ. Still further to the north-west there rises from the alluvial land a ridge of friable sandstone, the first outlier of a denuded sheet of sandstone, numerous remains of which again appear in the north superposed upon Rhaetic coal beds; to the west of the sandstone ridge rises another granulitic mountain near Tay-Ninh. On the west side of the great river between Chaudok and Rach Gia a group of granulitic and granitic hills again occurs, accompanied by the same sandstone; to the north-west of this group, western Cambodia as far as it is known is covered over wide areas by the friable sandstone, resting upon upturned beds of limestone, which are assigned to the lower Carboniferous. The great island of

[1] F. Ratte, Note sur l'Indo-Chine, Bull. Soc. géol. de Fr., 1875–1876, 3e sér., IV, pp. 509–522; Petiton, Esquisse géologique de la Cochinchine française, du Cambodge (province de Poursat) et de Siam (province de Battambang), op. cit., 1882–1883, 3e sér., XI, pp. 384–399, map; E. Fuchs et E. Saladin, Mémoire sur l'exploration des gîtes de combustibles et de quelques-unes des gîtes métallifères de l'Indo-Chine, Ann. Mines, 1882, 8e sér., II, pp. 185–298, map; E. Jourdy, Sur la géologie de l'est du Tonkin, Compt. Rend., 1886, CII, pp. 937–939, and Bull. Soc. géol. de Fr., 1885–1886, 3e sér., XIV, pp. 14–20, plate; Note complémentaire, tom. cit., pp. 448–453.

Phoukok consists of the same sandstone; which also forms the Elephant mountain situated to the north of the island.

These heights, and especially the granulitic ridges and mountains between Baria and Bien-Hoâ, those of Tay-Ninh, and on the other side of the Mekong those of Chaudok, form an incomplete boundary about the vast alluvial region; or perhaps they should rather be regarded as representing islands and peninsulas united by the alluvial land which now alone forms the whole region up to its southernmost extremity. The part played by the great interior lakes of Cambodia in this extensive advance of the growing land is very peculiar. Fuchs has given a lucid description of the process. The sea once covered the area now occupied by the alluvium of the Mekong. The mouth of the river then lay far to the east of the great lakes near the existing province of Pnom Baché; the heights of the existing province of Kompong Soai, composed of granitic rocks and quartz porphyry, separated the mouth from the great lakes which then formed the most northerly part of a gulf penetrating deep into the land. The advance of the river deposits cut off this part of the gulf from the open sea. The river Tonle Sap, which at present joins the Mekong near Pnom Penh and unites that river with the lakes, has so trifling a fall that during one part of the year it bears the high waters of the Mekong northwards into the lakes and for the other part of the year it carries the overflow of the lakes southwards into the Mekong. The direction of the waters is reversed as soon as the Mekong rises near Pnom Penh to a height of 7–8 meters above mean level; but it rises every year to a height of 12–14 meters above this level.

There is a great dearth of information concerning Annam. We know that a hilly ridge of granite accompanies the coast, that ancient schists occur along its eastern side on the river Tourane near Huë, and that coal-bearing deposits are also present which probably correspond with those of Tongking.

The plain of Tongking is much better known. Friable shales with few fossils are assigned to the Devonian, but this determination needs confirmation. A very prominent element is a hard limestone resembling marble, which projects in bluff rocks from many parts of the delta and forms outside it innumerable reefs and islands. Fossils of the Carboniferous limestone have been found in it by Jourdy. Above it lie calcareous shales intercalated with sandstone and containing fossils which, according to Douville, are closely related to *Myophoria Goldfussi* of the Keuper. I shall shortly have to refer to similar Myophorias obtained by Lóczi from Tshung-tien in Yunnan. There now follow sandstone and shales which form the coal-bearing series of Tongking. Zeiller has examined the flora of these beds, and has arrived at the remarkable result that 10 to 12 species correspond with those of the Rhaetic stage of Europe, while an equal

number are known in India, on the horizon of either the upper beds of the lower Gondwána or the base of the upper Gondwána. The number of new species is comparatively small[1].

This series of strata is thrown into folds which strike south-west to north-east; they reach the sea, and Jourdy indicates their continuation on Hainau, but on what grounds I have no information. According to the same observer this system of folds striking north-east is traversed by fractures which run from north-west to south-east, at right angles to the folds.

Deposits of more recent age than the Rhaetic coal-measures are so far not known in these regions.

6. *The Philippines.* The observations made in Celebes and Halmahera so far known to me are not sufficient to hazard even a conjecture as to the structure of these islands. We only know that ancient rocks such as granite and ancient schists are present, and a large number of recent volcanos, many of them still active.

The accounts of the *Philippines* are much more complete, but here again we are unable to form any definite opinion as to the structural plan. The Philippines have so far furnished no fossil remains of the Palaeozoic or the Mesozoic period. Superposed upon gneiss, talc-schists, serpentine and widely distributed gabbro and diabase, lies a sedimentary series which consists of a zone of limestone conformably overlaid by coal-bearing beds of unknown age, further of Nummulitic limestone, a more recent coral limestone reaching a height of 4,000 feet, which I correlate with the middle Tertiary coral limestone of the Banda islands and Borneo, and finally recent marine sediments. These formations are associated with a varied series of volcanic rocks which date at least from the Nummulitic period.

All observers are agreed that the ancient formations are to be regarded as forming, not a table-land, but a number of chains. Of these chains, however, only fragments are to be seen; the sea conceals a large part, and another part is smothered up under ashes and tuff ejected from the recent volcanos. The outlines of the islands do not everywhere correspond with the strike of the ancient formations, but have been affected in many ways by the presence of volcanic masses; this is particularly the case in the southern part of Luzon.

In 1878 R. von Drasche, in a compendious description of Luzon, represented the Philippines as a number of chains which in the north of this island are closely crowded together and run nearly north and south, but diverge in virgation towards the south and south-west. 'In north and central Luzon, the north and south direction predominates; in the south

[1] R. Zeiller, Examen de la Flore fossile des couches de charbon du Tong-king, Ann. Mines, 1882, 8e sér., II, pp. 292–352, plate; also Bull. Soc. géol. de Fr., 1882–1883, 3e sér., XI, pp. 456–461, and 1885–1886, 3e sér., XIV, pp. 454–463, plate.

the islands diverge from one another radially like a fan, and a gradual turning round may be observed from north-west and south-east to north-east and south-west, so that the directions of the strike in Palawan and south Luzon, the opposite ends of the fan, are perpendicular to one another.' The eastern branches are thereby bent more strongly to the east, and Drasche emphasizes their tendency to adapt themselves to the course of the coast of Annam in the same way as New Zealand and New Caledonia do to the east coast of Australia[1].

Subsequent observations seem to confirm this conception. To arrive at a clear idea of the position of the several chains, we must bear in mind two conspicuous lines of depression, which as early as 1869 were definitely marked by Semper on his general map of the islands[2]. The first of these lines corresponds with the longitudinal depression which runs through the west of Luzon from the bay of Lingayen to that of Manila, and marks off a mountain chain, the sierra de Zambales, from the rest of the island. The second line corresponds with the depression which occurs in the eastern part of Mindanao, and runs, interrupted by a watershed of no great height, from the bay of Butuan in the north to that of Davao in the south. This also bounds an independent mountain chain which strikes almost north and south from cape Surigao to cape St. Augustine.

The sierra de Zambales in west Luzon was crossed by Drasche in two places; it consists chiefly of gabbro and talc-schist with serpentine; great masses of trachytic tuff rest on its eastern slope. Its southern extremity, projecting into the gulf of Manila, is however of recent volcanic origin, and must be disregarded in considering the direction of the chain. The longitudinal depression is broad; it presents recent marine deposits, as observed by Centeno; Arayat, an isolated volcano, rises out of its plain[3]. It appears to have been in this more independent branch of the sierra de Zambales, which curves in an arc towards Palawan, through Luban and the Calamianes, that Tenison Woods observed ancient limestone[4]. The island of Palawan is formed, according to Centeno, by a long continuous sierra. This arc of Zambales-Palawan, the most westerly of the virgation, does, in fact, take a course which corresponds in a striking manner to that of the coast of Annam.

[1] R. von Drasche, Fragmente zu einer Geologie der Insel Luzon (Philippinen), 4to, Wien, 1878, p. 3. The oldest geological account of the Philippines known to me is that by the mining engineer, I. Sainz de Baranda, Islas Filipinas, 8vo, Manila, 1840. In 1873 Roth attempted to give a brief account of them from Jagor's collections; this excellent description, however, has little reference to the tectonic relations; J. Roth, Ueber die geologische Beschaffenheit der Philippinen, in F. Jagor, Reisen in den Philippinen, 8vo, Berlin, 1873, pp. 333–354.

[2] C. Semper, Die Philippinen und ihre Bewohner, sechs Skizzen, 8vo, Würzburg, 1869.

[3] J. Centeno, Memoria geológico-mineral. de las Islas Filipinas; Bol. Com. Mapa geol. España, 1876, III, pp. 181–234, map, in particular p. 184.

[4] Tenison Woods, Nature, Jan. 7, 1886, p. 232.

In the north of Luzon two great cordilleras, separated by the Rio Grande de Cagayan, extend as far as the latitude of the gulf of Lingayen, then unite, and for a certain distance follow the east coast. Further to the south the mountains are very much broken up and overlaid by extensive volcanic masses, but the strike to the south-south-east appears clearly in a long band of Nummulitic limestone interbedded with trachytic tuff, which may be traced from the province of Bulacan across the Laguna to Majaijay. Richthofen was the first to note its existence [1].

Drasche supposed that the outline of Masbate was due to bifurcation, and this would correspond with the structure of Porto Rico in the Antilles; but the structure of Masbate is unknown.

Zebu has been described in detail by Abella. The oldest rocks are diorite and dioritic tuff; they form two considerable masses in the centre of the island and a smaller mass at its southern end, and are surrounded by beds containing Nummulites. More recent limestone forms the remainder of the island, that is, by far the greater part; in some places it lies horizontal, in others it is upturned like the Nummulitic beds. The lignites of Zebu have also been placed in this group, which would thus include deposits of various age. The strike of the rocks corresponds on the whole with the outline of the island, and thus to the direction of one of the middle branches of the virgation [2].

The coal beds also make their appearance, according to Centeno's observations, on the adjacent island, Isla de Negros, and traces of them are known on the western part of Mindanao, north of the bay of Sibaguey. It is possible that a part of western Mindanao may prove to be the continuation of Zebu and the Isla de Negros.

The gold-bearing hill range of Pigholugan, near the gulf of Macajalar in Mindanao, that is nearly in the middle of the north coast of the island, consists, according to Abella, of ancient quartzite and clay slates which strike north-north-east and south-south-west [3].

The eastern sierra of Mindanao, which lies beyond the two bays of Butuan and Davao (or Tagloc), was visited by Montano; from its northern extremity it proceeds to the south-south-east, and then turns due south; it consists of greywackes, ancient schists, primitive limestone, serpentine, quartz, porphyry, and melaphyre. This mountain range must probably be regarded as the continuation of the island of Leyte [4].

[1] F. von Richthofen, Ueber das Vorkommen von Nummulitenformen auf Japan und den Philippinen; Zeitschr. deutsch. geol. Ges., 1862, XIV, p. 358 et seq.

[2] E. Abella y Casariego, Rapida descripcion física, geológica y mineral. de la Isla de Cebu; Bol. Com. Mapa geol. España, 1886, XIII, pp. 1–187, map.

[3] Id., Memoria acerca los criaderos auriferos del segundo distrito del departamento de Mindanao; op. cit., 1879, VI, pp. 33–79, maps, in particular p. 60.

[4] J. Montano, Rapport à M. le Ministre de l'Instruction publique sur une mission aux îles Philippines et en Malaisie; Archives des Missions, 1885, 3e sér., XI, pp. 271–479, maps, in particular pp. 271–277.

Still further towards the exterior lies a second band of coal-bearing beds which strikes to the south-east, and has been traced by Centeno from the region of Caramuan, across the island of Batan, and across Sugud in south Luzon into the island of Samar.

If we transfer these observations to a map, we attain a virgation from south-west in Palawan to south-east in the zone of the coal beds of south Luzon and Samar.

It is not improbable that the most westerly arc, Zambales-Palawan, is continued to Borneo. Such a continuation is less certain for the mountains of west Mindanao and Basilan; Yolo consists, according to Itier, of coral formations resting on basalt[1]. The prolongation of the eastern chain of Mindanao towards the south is only indicated by volcanos: on the west coast of the bay of Davao, the cone of Apo rises, according to Montano's measurement, to a height of 3,143 meters; it forms the highest peak of the Philippines. The volcanic zone would now seem to extend through Butulan and the island of Sangir to the volcanos of northern Celebes.

It was generally assumed by earlier writers, that a single zone of volcanos extended in an arc through the Philippines to the north; but the case is not so simple. Centeno considers that there are two chains of volcanos which should unite in south Mindanao. The western chain begins on the Buguias, north of Lingayen bay, and includes the volcanos of Arayat and Taal, Canlaon on the Isla de Negros, the island of Fuego, the volcano de Macaturin in Mindanao, and the volcano of Cotabato; this line has been named the system of the Taal. The eastern chain is the system of the Majon (Albay), and extends from the Isaro in south Luzon past Albay and Bulusan, the solfataras of Leyte, the volcano Camiguin north of Mindanao, which first arose in 1871, then to Apo and Butulan. The solfataras in the trachytic mountains of the island of Bitisan, which have recently been described by Abella, might then be regarded as inserted into this zone. Abella, however, conceives the continuation of this line as drawn not through Camiguin, but further east, following the direction of the island of Leyte towards Mindanao[2], and Drasche's geological map of south Luzon shows so many volcanic eruptions of such various description, that it is difficult to find definite guiding lines in this region. The clearest line of this kind makes its appearance in south-east Luzon between the Isaro and the Bulusan, and is continued towards Biliran; it lies completely in the strike of this part of the virgation[3].

[1] J. Itier, Extrait d'une description de l'archipel des îles Solo; Bull. Soc. géogr., Paris, 1846, 3e sér., V, pp. 311–319.

[2] From Montano's last description one would certainly be inclined to doubt that lake Mainit on the peninsula of Surigao (N. Mindanao) is really a crater.

[3] Drasche, p. 72, assigns to this line the closely adjacent volcanos of Labo, Isaró, Iriga, Mazaraga, Albay, and Bulusan.

Further to the north of Luzon, in about lat. 18° 10′ N., where Cabo del Engaño begins to jut out, stands the volcano de Cagua. Towards the north-west there follow the volcanic island of Babuyan, then the Batanes islands, and finally the great island of Formosa.

7. *Formosa and the Liu-Kiu islands.* *Formosa* is still unfortunately but little known; the observations of Swinhoe, Richthofen, and Tyzack are confined to isolated localities in the north[1]. Monkey mountain or Taku Shan, on the west coast, has been described by Guppy[2]; Kleinwächter has visited the south part of Formosa[3]. An important mountain range which, according to some statements, reaches a height of 10,000 feet, according to others of 12,000 feet, extends through the eastern part of the island towards the north and north-north-east. The east coast is in places very steep, and near Chokeday (lat. 24° 10′ N.), according to Richthofen, it descends precipitously from heights of 6,000–7,000 feet into the deep sea. On the other hand, the whole western side of the island is low, and the plain is only interrupted by isolated hills formed of coral limestone.

Kleinwächter reached the slopes of the Kueili Shan, the highest peak (about 9,000 feet) in the southern half of the mountain chain, and he found that this consists of folded hornblende-schists and clay slates, together with quartz porphyry. The pebbles of the river Tamsui show that further north granite also enters into the structure of the range. Against these mountains there rest in the south, first quartzose sandstone, and then coral limestone, of which the two southern promontories of Formosa consist. We have already mentioned that coral limestone forms the isolated mountains of the western plain; it is assigned, as a rule, to the Tertiary; and it also forms the island of Lambay, lying off the west coast. In the isolated Monkey mountain, cavernous limestone with Scutella, Balanus, and corals rises 1,100 feet above the sea in beds which dip 35° to 40° E. In the north of the island, on the Kilung river, middle Tertiary coal-seams are being worked; they lie in a synclinal with steeply inclined limbs; these, like those of Monkey mountain, show that Formosa must be included among the regions which have experienced folding in recent times.

[1] Robert Swinhoe, Notes on the Island of Formosa, Journ. Roy. Geogr. Soc., 1864, XXXIV, pp. 6–18, map; F. von Richthofen, Ueber den Gebirgsbau an der Nordküste von Formosa, Zeitschr. deutsch. geol. Ges., 1860, XII, pp. 532–545; D. Tyzack, Notes on the Coalfields and Coal-mining operations in N. Formosa, Trans. N. Engl. Inst. Eng., Newcastle, 1884–1885, XXXIV, pp. 67–79, map; and J. A. Lebour, Notes on some fossils from N. Formosa collected by Mr. D. Tyzack, tom. cit., pp. 81, 82. Arthur Corner mentions a Palaeozoic fossil, *Monotis Hawni*, from the neighbourhood of Monkey mountain, but this discovery is so far unconfirmed; A Journey in the Interior of Formosa, Proc. Geogr. Soc., 1874–1875, XIX, p. 515.

[2] H. B. Guppy, Some Notes on the Geology of Takow, Formosa; Journ. N. China Br. R. As. Soc., Shanghai, 1881, new ser., XVI, pp. 13–17.

[3] G. Kleinwächter, Researches into the Geology of Formosa; op. cit., 1884, new ser., XVIII, pp. 37–53, map.

At the mouth of the river Tamsui, Richthofen observed trachyte and horizontally bedded trachytic tuff. The great solfataras, north-west of Kilung, probably also proceed from trachyte [1]. These trachytes are the only recent volcanic rocks known in Formosa, and the early statements as to the presence of active volcanos in the island have not so far been confirmed. Kleinwächter, it is true, mentions that on the flat coast near Langchiao flames often break forth from the baked ground, but he conjectures that they are due to gases which accompany petroleum. The Chinese statement that in the year 1722 flames and mud burst forth on the Chih Shan or Pineapple hill, near Takow, may perhaps be explained in the same way. Petroleum is, in fact, known to occur in the north near Tangshui below Tamsui. All these localities belong to the west coast.

The *Pescadores* islands consist, as Edmund Naumann kindly informs me, of alternating layers of basaltic tuff and coral limestone.

While the north to south trend of Formosa might, perhaps, suggest a continuation of the northerly direction of north Luzon, the southern extremity of the great arc of the *Liu-Kiu* islands already deviates considerably from this direction. Döderlein has recognized the important fact that in the whole northern part of this arc, i.e. from about lat. 25° 30′ N. to as far as Kiushiu, we may distinguish between an outer series of islands, turned towards the great Ocean, and an inner series. The outer series comprises the great non-volcanic islands of Okinawa-shima, Tukono-shima, Amami-o-shima, Yakuno-shima, and Tanega-shima, while the inner chain is formed of smaller islands, which so far as they are known are of volcanic origin; such are (perhaps) Kume-shima, then the volcano Tori-shima (Sulphur island), then (probably) the Linschotens, Erabu-shima, Kose-shima, Yuo-shima, Tage-shima, and directly joining the arc we meet with Satsuma—Fujiyama on Kiushiu, the volcano Sakura-shima, which forms an island in the gulf of Kago-shima, Kiri-shimi-yama, and finally the famous Aso-yama in Kiu shiu [2].

Thus in the arc of the Liu-Kiu islands that arrangement is repeated which we have already observed in the Antilles, the Nicobar and Andaman islands, and the Banda islands, and which is so closely paralleled in the Carpathians and the Apennines. The fragments of the cordillera stand on the exterior, the volcanos on the inner side. At the same time the extension of the arc into Kiushiu is unmistakable, and the south-east part of Kiushiu appears to be the continuation of the outer zone of the Liu-Kiu islands.

In *Okinawa* Perry and Jones met north of Nafa with gneiss, clay slates, and beds possibly containing coal: the most striking feature in the land-

[1] Several travellers have described the rock as porphyry.

[2] L. Döderlein, Die Liu-Kiu-Insel Amami Oshima; Mitth. deutsch. Ges. Ostasiens, Yokohama, 1881, Heft 24, 31 pp., map, in particular p. 2.

scape of the island, however, is formed by a steep ridge of fossiliferous limestone 400 to 500 feet high, which is broken up into a number of jagged peaks, probably by the same process of erosion as forms 'Karrenfelder' or grykes; it runs through a great part of the island, directed N. 50° to 60° E. The gneiss is strongly folded [1].

Amami-o-shima, according to Döderlein, is mountainous and consists of gneiss, granite, granulite, and crystalline schists. Clay slates steeply upturned are to be seen on the east coast.

8. *Japan.* The islands of Japan, together with New Zealand, are peculiarly well adapted to throw light on the structure of the wonderful island arcs which surround the Pacific Ocean, for they consist of fragments of simple cordilleras; the general plan is not complicated by virgation as in the Philippines, and fragmentation has not advanced so far as in the Banda islands and the arc of the Liu-Kiu islands. Fortunately we possess a recent account by Edmund Naumann. It is based on the result of many years of arduous work carried on with the co-operation of able Japanese geologists and contains a large number of fresh observations [2]. The author has very kindly furnished me, both in written and oral communications, with additional information on many points, so that it is on his observations together with Milne's account of the volcanos of Japan [3], and the much older map of Yezo by Lyman [4], that the following description is chiefly based.

In the configuration of Japan a certain symmetry may be easily recognized. The great island of Hondo, bent in a gentle arc, is accompanied on the north-east as on the south-west by an extensive island—Yezo on

[1] M. C. Perry, Narrative of the Expedition of an American Squadron to the China Seas and Japan, compiled by F. L. Hawks, 4to, Washington, 1856, I, pp. 184, 311; G. Jones, Report on a Geological Exploration of Lew-Chaw, op. cit., II, pp. 53–56; and Döderlein, op. cit., p. 27. Élie de Beaumont quotes fossils collected by the missionary P. Furet at Nafa in Okinawa, the age of which, however, cannot be regarded as certainly established; Compt. rend., 1859, XLVIII, p. 287, and J. Marcou, Lettres sur les roches du Jura, 8vo, Paris, 1857–1860, p. 269. The coral limestone, 200 feet above the sea and far distant from it, is mentioned by R. H. Brunton, Notes taken on a visit to Okinawa Shima, Loochoo; Trans. Asiat. Soc. Japan, Yokohama, map, 1876, IV, pp. 66–77, in particular p. 72.

[2] E. Naumann, Ueber den Bau und die Entstehung der japanischen Inseln, 8vo, Berlin, 1885, 91 pp.; by the same, Die Erscheinungen des Erdmagnetismus in ihrer Abhängigkeit von der Erdrinde, 8vo, Stuttgart, 1887, in particular p. 15 et seq.; Geological Survey of Japan, Reconnoissance map, Geology, Division I, by E. Naumann, assisted by Takao Fujitanai, Akira Yamada, Ichitaro Ban and Shogo Nishiyama (publication not yet complete). A little geological sketch-map of earlier date appears in J. G. Godfrey, Notes on the Geology of Japan; Quart. Journ. Geol. Soc., 1878, XXXIV, pp. 542–554.

[3] J. Milne, The Volcanos of Japan; Trans. Seis. Soc., Japan, Yokohama, 1886, IX, pt. 2, 184 pp., maps.

[4] B. Smith Lyman, Geological Survey of Hokkaido, A geological Sketch-Map of the Island of Yesso, Japan, fol., Tokei, 1886.

the one hand and Kiushiu on the other, and each of these advances a little further towards the Ocean than the adjacent end of Hondo.

As we have already seen, the arc of the Liu-Kiu islands extends from the south-south-west into the island of Kiushiu, so that some of the volcanos of Kiushiu must be regarded as a part of the arc of Liu-Kiu.

FIG. 17. *Japan.*

The closely cross-hatched zone traversing the middle of Honshiu indicates the 'great foss;' the zone with simple hatching which runs through Shikoku and Kii, shows the strike of the crystalline schists. The caldrons of the west coast (Iwaki, Morioshi, and others) are indicated by lighter cross-hatching.

At the same time the south-east part of Kiushiu forms the continuation of the outer zone of ancient rocks of this arc, that is of Okinawa-shima, Amami-o-shima, &c., and in fact this zone approaches in the island of Tanega-shima quite close to the south coast of Kiushiu.

Similarly the volcanic arc of the Kuriles coming from the north-east

enters into the body of Yezo. The connecting link is formed near Nemuro by the peninsula jutting out of the eastern half of Yezo, and Milne mentions four volcanos in the eastern part of Yezo, two of them active, which must be included in the range of the Kuriles [1].

The seas which surround Japan, particularly the adjacent part of the Pacific Ocean, are of very great depth; in fact the oceanic abysses sounded here are among the deepest known, while the island-strewn gulf which penetrates into the interior of Hondo has a depth of only 30 fathoms. This gulf, therefore, is due to only a slight submergence, which has followed indeed the trend of the arc.

The gulf or inland sea is separated from the Ocean on the south by the large island of Shikoku, and this is followed on the east by the peninsula of Kii which agrees with Shikoku in structure. The middle of the Pacific coast of Hondo is met by the chain of volcanic islands, which includes the island of O-shima; this we will call the Shishi-to chain. North of the bay of Tokio the coast trends more and more to the north, and bulges out in two broad projections separated by the bay of Sendai. The southern of these regions which protrude out of the general course of the arc, we will call with Naumann the Abukuma mountains, that north of the bay of Sendai the Kitakami mountains.

The holy mountain Fujiyama, with its symmetrical ash-cone rising 12,400 feet high, marks the region in which the volcanic chain of Shishi-to meets the middle of Hondo. A mighty line of division here cuts across Hondo from side to side; it is signalized by a great accumulation of volcanic products and is of the first importance in a study of the structure of the chain. Naumann speaks of it as the great region of fracture or the 'great foss': it divides the island into two moieties, which we will call north Japan and south Japan.

Shikoku and Kii, situated on the south-east coast of Hondo, are formed of stratified zones striking to the east-north-east; Radiolarian slates of Palaeozoic age, upper Carboniferous limestone, Trias, Jurassic, Cretaceous, and some Tertiary beds are present; they are thrown into folds, either normal or slightly overturned towards the Ocean, and form in a quite unmistakable manner the outer zone of a mountain chain folded in the direction of the Ocean, that is to the south-east. Mesozoic deposits occur also as narrow bands pinched into the Palaeozoic complex. Behind these folded beds, that is towards the interior, a zone of crystalline schists very steeply upturned runs through Shikoku and Kii: characterized by great resistance, they stand out in the configuration of the country and form the long tongues or peninsulas which proceed from both sides of Shikoku as well as of Kii, and constrict the passage from the Ocean to the interior

[1] These are: Iwo-san, active, with a caldron of boiling mud and sulphur, Kusuri, Oakan, with a regular conical form, and Meakan, an active cone.

sea. From the western part of Shikoku in particular a long spur extends towards the east of Kiushiu, and a glance at the map will show that in spite of the penetration of the Liu-Kiu arc into Kiushiu, the general strike of the folded ranges of south Hondo is also continued into a part of this island.

The continuous course of this more resistant zone of schist, with its wing-like projections, gives to Shikoku the form of a double rhomb and to Kii of an irregular simple rhomb. I mention this fact because the same causes have produced the lozenge-like form of the isle of Wight, which is also due to the prominence of more resistant beds, and because we shall meet with the same phenomenon on a larger scale in the outlines of Yezo.

The rocks of the outer zone of Shikoku and Kii are continued still further through Shima, which is formed by the eastern spur of Kii, but towards the great division in the middle of Hondo the strike bends from east-north-east to north-east and finally to north-north-east, and so describes an arc such as is usually formed by folds about to meet a second mountain range in syntaxis. Since this segment of the chain, bent in an arc, is cut off by the zone of division or fracture which strikes N. 25° W., a wedge results which Naumann calls the Akaishi sphenoid.

On the inner side of the long schist range of Shikoku and Kii older rocks occur, principally granite, which is weathered into a number of rounded summits and rises in innumerable islands out of the interior sea. The ranges lying towards the Japanese sea also consist of granite, ancient schists, quartz porphyry, and ancient massive rocks of various kinds. The north coast is distinguished by a few caldron-shaped subsidences, among which that of the volcano Daisen and the Sampei caldron may be mentioned in particular. The strike of these inner zones corresponds with that of Shikoku and Kii, with the same deflexion towards the region of fracture. On Kiushiu a cluster of recent volcanos in the middle of the island corresponds to the continuation of the interior sea. In the north-west of Kiushiu, Naumann believed he had seen a great granitic laccolite; certainly a considerable part of the Japanese granites first made their appearance towards the close of the Palaeozoic period.

Naumann believes that it is the Chinese chains, striking out in the Tshu-san islands, which are continued through Kiushiu into the chain of south Hondo. A further examination of Kiushiu will show us in what way the arc of the Liu-Kiu meets it, whether directly or in syntaxis.

We have now reached the region of fracture. The line of the Shishi-to volcanos, coming from O-shima, the last great eruption of which took place in January, 1877, meets the peninsula of Izu; here rise Amagi-san (4,700 feet), Hakone-yama (4,474 feet), Ashidaka-yama and the mighty Fuji-san. These are followed by a serried row of numerous other great volcanos, among them Yatsuga-taka (9,114 feet) with its twin peaks, Asama (8,800

feet) where an eruption occurred in 1870, Renge-san (9,800 feet) with two craters, Tate-yama (9,400 feet) which stands on granite, and others[1].

On the other side of the great foss the structure of south Japan is repeated in its main lines. The Abukuma mountains and the Kitakami mountains consist of a series of fossiliferous rocks similar to those of Shikoku and Kii, and similarly thrown into folds, which strike parallel to the general direction of this part of the island, that is fairly to the north. Towards the south, in the mountain region of Quanto, the folds are bent back towards the zone of fracture as in the Akaishi sphenoid on the other side of this zone. In this case, however, the bending back is accomplished by a change from north and south, first into a south-west and then finally into a north-westerly direction; the north-westerly strike of the inner zones persists nearly to the middle of north Japan. The central region, however, which should correspond to the position of the interior sea, is occupied by a long series of volcanos which we will term the meridional chain of north Japan. A group of five volcanos rises in the south towards the fractured region near the beginning of this chain; the highest mountain of this group, Shipane-san (8,500 feet), was in eruption in 1872; Milne mentions 21 volcanos in the meridional chain. A part of western Yezo also belongs to it, with 13 volcanos, many of them active.

Finally the west coast of north Japan is characterized by four great caldron insinkings, each of which encloses a great volcano; these are, from south to north, Gwassan, Chiokai (7,100 feet), Moriyoshi (5,800 feet), and Gunju-san (7,000 feet), which gives off a little steam; its last eruption was in 1824. These caldrons which have been let down into the ancient rocks of the inner side of the chain are similar in every respect to the bays of Naples, Salerno, Santa Eufemia, and Algiers, and the other caldron inbreaks which surround the western Mediterranean on the inner side both of the Apennines and of the cordillera of north Africa.

We thus see that south Japan consists of a cordillera of unilateral structure, folded towards the Ocean: its subsidences are represented on the inner side by the caldrons of the Sampei and Daisen; its inner zone appears in Chugoku and is marked by the granite rocks of the interior sea; its outer zones lie in eastern Kiushiu, in the mountainous country of Shikoku and Kii, and bend inwards in the Akaishi sphenoid to meet in syntaxis a second cordillera, that of north Japan. North Japan also is traversed by a cordillera; the subsidences on its western inner border are marked by great caldrons from the Gwassan to the Iwaki; its outer zones start from the syntaxis in the mountainous country of Quanto, describe an arc, and then proceed through the mountains of Abukuma and Kitakami.

[1] Several of the volcanos in the great fractured region have been described by R. von Drasche in Bemerkungen über die japanischen Vulcane Asama-Yama, Jaki-Yama, Iwawasi-Yama und Fusi-Yama; Tschermak's Min. Mitth., 1877, pp. 49–60.

The syntaxis indicated by the inflexion towards the interior exhibited both by the Akaishi and the Quanto region, but in opposite directions, is distinguished from all other cases of syntaxis by the fact that a large part of the syntactic region has subsequently collapsed and great volcanos have arisen in the trough, on the continuation of the Shishi-to chain.

There is some difference of opinion, not as to the facts but as to the precise manner of interpretation. Naumann prefers to regard the great trough not as a recent subsidence but as a very ancient fissure, although not so old as the main longitudinal fracture of the whole range, and he assumes the presence of a pre-existing obstacle to the folding, somewhere in the position of the Shishi-to chain. Harada, however, adopts the same explanation as we have given above[1].

Milne has incidentally made a comparison between the Shishi-to chain and the Ladrones; this would involve the existence of another insular arc, syntactic with the arc of south Japan, and syntactic against that of north Japan. But such a supposition does not accord with the existence of the downthrown syntactic fragments encountered within the fractured region; and still less with the aspect presented by other regions of syntaxis.

Our knowledge of Yezo is unfortunately less complete than that of Hondo. Pumpelly, who some time ago examined the south part of the island, encountered on the southern peninsula, between Hakodate and Volcano bay, a range of ancient schists with quartz porphyry and greenstone which strikes to the north-west and must probably be regarded as the continuation of the northern arc of Hondo.

This band is surrounded by more recent volcanos and by recent marine deposits arranged in terraces[2]. From Lyman's map we may conclude that a long range of folded rocks strikes across the island through its greatest breadth towards the north-north-west in the direction of Saghalin. The island owes its lozenge-like form to this great range, thus recalling Shikoku, Kii, and the isle of Wight. We must perhaps regard it as the continuation of Saghalin. It has also been represented as the continuation of the northern arc of Hondo carried further towards the Ocean, but the fragment striking to the north-west, which Pumpelly observed near Hakodate, does not support this conjecture. We also know from Naumann that in central Yezo the middle Cretaceous covers a large area and is probably directly superposed on ancient rocks. In like manner, according to the investigations of F. Schmidt and P. von Glehn, the Cretaceous in the south part of Saghalin attains a very wide development, and the

[1] Naumann, Erdmagnetismus, p. 18; Harada-Toyokitsi, letter in Anz. k. Ak. Wiss. Wien, July 7, 1887.

[2] R. Pumpelly, Geological Researches in China, Mongolia and Japan; Smithsonian Contributions, No. 202, 1866, p. 79 et seq., in particular p. 106, pl. viii.

impression made on Naumann also was that this Cretaceous of Saghalin would be found to traverse the whole of Yezo or would certainly be continued into the peninsula. Pending further information, however, it would be well not to directly connect Saghalin and the principal chains of Yezo with the principal chain of Hondo, but to regard them as forming an independent feature lying further to the east and distinguished by a considerable development of the Cretaceous [1].

In conclusion we know that a part of the east of Yezo belongs to the volcanic arc of the Kuriles.

9. *The Kuriles and Kamchatka.* The Kuriles have been visited three times by Milne. They contain twenty-three well-formed cones, sixteen of them smoking, arranged in a long arc. Sedimentary beds or older rocks have not been encountered; the elongated islands, such as Iturup, 216 kilometers long, appear to have been formed by the action of marine currents which, flowing parallel to the arc, have united the cones by piling up the ashes between them [2].

The island of Paramushir, more than 90 kilometers long, consists of a series of extinct volcanos, with one crater still smoking, directed to the north-east and surrounded by an accumulation of ashes and lavas. Only a narrow arm of the sea separates this island from the flat island of Shumochu, which follows on the north-east and also consists of ashes and lavas; this in its turn is only separated from cape Zopatka, the southern point of *Kamchatka*, by a channel of no great depth, due to marine erosion. North-west of Paramushir there rises out of the sea the steep isolated cone of Alaid, which last broke into eruption in 1793. These are the most northern of the Kuriles, and now the great train of volcanos, which we have been able to trace from the east of Yezo, enters the peninsula of Kamchatka. The series proceeds through the eastern part of the peninsula, comprising according to Dittmar thirty-three volcanos, twelve of them active [3]. The most northerly of these are the Kljutshewska

[1] For Saghalin: F. Schmidt, Sachalin; Baer und Helmersen, Beiträge zur Kenntniss des russischen Reiches, 1868, XXV, p. 177 et seq.; P. von Glehn, Reisebericht von der Insel Sachalin, tom. cit., p. 189 et seq., in particular pp. 203–277; also Schebunin's map of Sachalin; further, F. Schmidt, Ueber die Petrefacten der Insel Sachalin, Mém. Ac. Imp. Saint-Pétersb., 1873, 7e sér., XIX, No. 3. For Yezo: E. Naumann, Ueber das Vorkommen der Kreideformation auf der Insel Yezo (Hokkaido), Mitth. deutsch. Ges. Ostasiens, Yokohama, 1880, Heft 21; and by the same, Bau und Entstehung der japanischen Inseln, p. 21.

[2] Milne, A Cruise among the Volcanos of the Kurile Islands; Geol. Mag., 1879, 2nd ser., VI, pp. 337–348, map; and Volcanos of Japan, pp. 125–169, map.

[3] C. von Dittmar, Die Vulcane Kamtschatkas, Peterm. Geogr. Mitth., 1860, II, p. 66; also A. Postels Bemerkungen über die Vulcane der Halbinsel Kamtschatka, Mém. Ac. Imp. Saint-Pétersb., 1835, II, pp. 11–28, and Perrey, Document sur les tremblements de terre et les phénomènes volcaniques dans l'archipel des Kouriles et au Kamtschatka, 166 pp., 8vo, 1863 (in the Ann. Soc. agric. Lyon).

Sopka (lat. 56° 8′ N., 4,804 meters) and the Shewelutsh (lat. 56° 40′ N., 3,215 meters); both these great mountains have been described in detail by Erman[1]. In the axis of the peninsula a broad longitudinal valley, stretching to the north-east, corresponds to the upper course of the river Kamchatka; this river after following the valley for a great part of its length turns almost at right angles, and flowing to the east at the north foot of the Kljutshewska Sopka reaches the sea near Nishne Kamchatka. The series of active volcanos extends east of this valley to the Kljutshewska Sopka, and the Shewelutsh alone rises north of the lower course of the river.

Dittmar has published a general geological map of the peninsula, in which he has incorporated Erman's observations[2]. Judging by the structure of the Kiu-Liu, the Antilles, and other island arcs, we might expect the subsided cordillera of the Kuriles to become visible in Kamchatka on the east side of the volcanos. Dittmar does in fact mention ancient crystalline schists and similar rocks on all the peninsulas of the east coast to beyond lat. 58° N., with the exception of the broad cape Kronozkij, which is covered with ashes and lavas; granite and gneiss appear here and there at the very foot of the volcanos. Analogy would certainly lead us to regard these rocks in the east and those at the foot of the volcanos as the few visible remains of the cordillera of the Kuriles. Many ranges of granite, gneiss, and ancient schists of greater importance appear, however, to the west of the great volcanos, and in particular a long range lying west of the upper course of the Kamchatka river; this is apparently $2\frac{1}{2}$ degrees of latitude in length and accompanied by clay slates; to the north follow mountains of porphyry. These again are joined by recent volcanic ejections; between lat. 56° 10′ N. and lat. 57° 30′ N. there rises in the west a group of five extinct volcanos forming an independent western zone.

Two fragments of arc would thus appear to occur in Kamchatka—an eastern segment with the great active volcanos and the ancient rocks of the eastern promontories, representing the continuation of the Kuriles, and a western segment to which would belong the range of hills west of the Kamchatka valley, together with its prolongations and the extinct volcanos of the north-west; this is just what we find in Yezo, where indeed we were able to distinguish three successive arcs, one behind the other.

[1] A. Erman has already published a geological map which embraces Kamchatka in Erman's Archiv für wissenschaftliche Kunde von Russland, 1842, II; in the following volume there is a description of some fossils from Kamchatka by Girard.

[2] Dittmar, Ein paar erläuternde Worte zur geognostischen Karte Kamtschatkas; Bull. Ac. Imp. Saint-Pétersb., 1855, XIV, pp. 241–250, map. Professor Kreutz, of Cracow, has kindly sent me a list of the rocks collected by Professor Dybowski in Kamchatka and the Commander islands, and observes among them, from Tigil (Kamchatka), light grey compact siliceous limestone filled with Trochammina, Haplophragmium, Lagena, and other rhizopods.

The west coast in the neighbourhood of Bolsherezh, and even much further to the north, is flat. In the west and in the Kamchatka valley Tertiary coal beds with leaf imprints make their appearance. They also occur far to the north, on cape Tajganos and northwards as far as Ishiga, lying in patches on the granite and the ancient schists of the peninsula.

10. *General survey of the island arcs.* It follows from this investigation that in the north-east of Asia the following arcs may be distinguished:—

(*a*) The arc of the *Liu-Kiu* islands. This consists of the fragments of the cordillera which form an outer zone, and of the volcanic zone on the inner side; it extends into the south of Kiushiu.

(*b*) The arc of *south Japan.* Its outer zone extends from Kiushiu through Shikoku and Kii, and is bent backwards in the Akaishi sphenoid in the direction of a syntaxis against the great fractured region which distinguishes the middle of Hondo. Naumann supposes that it is continued to the folded ranges of south China which run out to sea near the Tshu-san islands.

(*c*) The arc of *north Japan.* The outer zones proceed from the fractured region, bending through the mountains of Quanto to continue through Abukuma and Kitakami. The inner zones bear the volcanic meridional chain and the west coast is characterized by caldron inbreaks. A part of the continuation of the arc directed to the north-west lies in the southern part of Yezo.

(*d*) The arc of *central Yezo and Saghalin,* situated somewhat nearer the Ocean, is distinguished by the development of the Cretaceous system.

(*e*) The arc of the *Kuriles.* The east of Yezo belongs to the arc which runs into southern and eastern Kamchatka as far as the volcano of Shewelutsh. It is represented as far as Kamchatka by volcanos only, but no doubt the zone of older rocks lying east of the Kamchatka river together with the volcanos may be regarded as a part of its cordillera.

(*f*) The fragment in *central and western Kamchatka.*

11. *The north of China.* The question now arises as to the relations of these island arcs with the mountain chains of the Asiatic continent. We were able to trace the Malay arc from Yunnan to the west coast of New Guinea. But the chains of the Philippines diverging towards the south presented no visible continuation on the mainland. The trend-lines of the northern arcs and the adjacent ranges of China have often been represented diagrammatically, but the schemes even of the most competent authorities, such as Pumpelly and Lóczi, differ completely from one another[1].

As the result of a laborious journey from the central Yang-tse-kiang through Peking into Mongolia, Pumpelly was able to confirm the statement

[1] Pumpelly, Geological Researches, &c., pl. vii; L. Lóczi, A Khinai birodalom természeti Viszonyainak és Országainak Leirása, 8vo, Budapest, 1886, p. 19.

of earlier travellers that the mountain chains of China strike chiefly from south-west to north-east (more exactly W. 30° S. to E. 30° N.), and he distinguished the mountains which follow this direction as the *Sinian system*[1]. But it will only be possible to obtain a general idea of this vast empire when Richthofen's comprehensive works have been completely published[2]. In the great work with which F. von Richthofen has enriched our science he has not only recorded observations accumulated during many years of travel, but has also attempted to analyse the structure of the land into its various elements and to determine the relations of these elements to one another. In the south, long folded ranges predominate, some striking out to the sea in the Sinian direction, i.e. to the north-east, the others in the south-west running from Ya-tshon-fu and further through Yunnan to the south-south-west, and as it now appears forming the beginning of the Malay arc. In the north, however, the structure of the country is much more difficult to interpret; particularly so north of Han-tshang-fu, where near lat. 33° N. the Sinian chains abut against the south side of the rectilinear chain of the Tsin-ling-shan, which trends east-south-east, and thence into the southern part of Mongolia. Fragments of ancient table-land are present, and folded ranges of different age and direction, as well as subsidences, also of different age. Richthofen has distinguished and defined these regions; master of a vast field of fresh observations, he has arrived at general conceptions which accord in the most happy manner with views on the origin of mountains simultaneously developed in other lands. Thus, what is described in China as a 'diagonal mountain,' i.e. as a mountain in which the direction of the folding does not correspond with the orographical outline, is in fact a horst, the visible remains of an ancient folded range. In a number of very important points the description of China has confirmed views already accepted in Europe. This is particularly true of Richthofen's statement, that in a country already folded fresh folds or even faults may be produced which follow the original direction[3].

No marine deposit of Mesozoic or Tertiary age is known anywhere in the north of China or in the south as far as Yunnan. The sediments of the lower or middle Jurassic contain only terrestrial plants and coal beds. They are directly succeeded by lacustrine deposits of very recent date, then by the loess and the alluvium of the great plain of the Hwang-ho. Even the Silurian and Devonian sediments have not yet been encountered between the Weiho and Mongolia, that is in the whole of China north of

[1] Pumpelly, op. cit., p. 67 et seq.

[2] F. von Richthofen, China, Ergebnisse eigener Reisen und darauf gegründeter Studien, 8vo, Berlin, I, 1877; II, Das nördliche China, 1882; IV, Paläontologischer Theil, 1883; Atlas, fol. 1, 1885.

[3] Richthofen, op. cit., II, p. 637.

the Tsin-ling-shan; in that region the Carboniferous lies immediately on the Cambrian beds, and is followed by the Mesozoic.

The several elements of the structure do not stand out very obviously, since a part of the interval between them is occupied by the shallow waters of the gulf of Pe-chi-li, an inland process of the Yellow sea, and another part is concealed by the alluvial land of the Hwang-ho. If we imagine this alluvial land to be submerged as far as the foot of the mountains, that is, to Peking, Hwai-king-fu, and Nanking, then the mountain mass of *Shan-tung* will rise out of the waters as an island.

This mountain mass is cut right across by a great fault along the Wei-ho. The western half shows the Archaean foundation covered by horizontal Cambrian and Carboniferous beds, and it sinks to the north along faults running in the same direction but not parallel. In east Shan-tung the Archaean foundation is laid bare; a folded chain trending to the north-east once existed here; it was denuded before the Cambrian period, and on its planed-down surface rests a horizontally stratified mass of Cambrian deposits[1]. Thus in Archaean times folding already existed here, and the strike of these primaeval folds does not differ materially from that of the recent folds in south Japan. Since the Cambrian period no folding has taken place in this region; fractures alone have occurred. West Shan-tung appears to be the downthrown part of a shattered horst, since here the sedimentary covering is more completely preserved. The fractures in west Shan-tung are, in part at least, of pre-Carboniferous age, as is shown by the transgressive bedding.

Liao-tung has the same structure as east Shan-tung and may be regarded as its continuation. Here, too, the fundamental rocks are folded, and we meet with superimposed patches of horizontal Cambrian beds; on the border of Korea these have furnished Trilobites[2].

The journeys subsequently made in *Korea* by Gottsche show that these deposits extend into north Korea; that by far the greater part of this peninsula consists of crystalline schists, and that, with the exception of the Tertiary lignite beds, the small patches of recent strata overlying them include no sediments of later date than those of north-east China[3].

[1] Richthofen mentions at several places a still older direction which is said to be recognizable in the most ancient gneiss; NE.–SW. is the strike of the folded mica-schists, primitive limestone, &c.

[2] Dames compares two localities with the lowest division of the American Potsdam sandstone; the third, from the presence of the genus Dorypyge, most closely corresponds to the Quebec group of Utah. He leaves it an open question whether this horizon should be assigned to the lower Silurian, or, as Barrande thinks, to the Cambrian; W. Dames, Cambrische Trilobiten von Liautung, in Richthofen, China, IV, p. 33.

[3] C. Gottsche, Geologische Skizze von Korea; Sitzungsber. k. preuss. Akad. Wiss. Berlin, XXXVI, Sitzung vom 15. Juli 1886, 17 pp., map. The island of Mackau in the archipelago lying south-west of Korea has been visited by Guppy; it consists of gneiss,

Thus on either side of the Yellow sea stands a primitive orographic mass, Korea with Liao-tung on the one hand and Shan-tung on the other; each is characterized by the fact that Cambrian sediments rest in horizontal sheets on an Azoic foundation. The structure of these regions is wholly different from that of the neighbouring Japan.

The accounts hitherto published do not enable us to speak with equal certainty of *Liao-hsi*, but pending further information, I have no hesitation in regarding the greater part of it as belonging to the next mountain fragment.

A region composed of parallel mountain chains has been graphically described by Richthofen as a grill or grid ('Rost'), and in this sense we speak of the grill of Peking. Its ranges strike E. 30° N. How far it is continued past Tshong-to-fu in the same direction into eastern Mongolia is at present unknown. To the north it is in great part covered by recent lavas, which appear outside the Great Wall in broad platforms, but beyond these platforms and even projecting from them fragments of the grill are still to be seen. To the west the grill ends suddenly against the plains of Ta-tung-fu and Hsin-tshou, along a line which cuts the strike of the ranges transversely. The direction which is distinctive of the grill dates from a very early period, for while the gentle undulations of the gneiss maintain the characteristic direction, e. g. in the lofty mountain of Wu-tai-shan, the Cambrian beds lie flat. But of much greater importance, as regards the existing form of the grill, than these ancient folds appear to be the flexures and longitudinal fractures with dragged-back edges which follow the original direction, and throw down the whole region in successive steps from Mongolia towards the great plain.

These subsidences possibly date from different periods; in any case they are much more recent than the pre-Cambrian folds.

The mightiest and longest range of the grill begins in the south-west with the gneiss dome of *Wu-tai-shan*, which is over 10,000 feet in height and lies north of Hsin-tshou; this is continued to the north-east in the Hsian-wu-tai-shan, and then in the Nankou chain, which sinks in the south-west by a great flexure to the plain of Peking. The range of Wu-tai-shan is followed on the south by that of Hsi-tshou-shan, which is doubtless continued to the north-east in the granite ridge of Hong-shan. The latter, instead of proceeding to the north-east like the others, collapses, and it is only on the other side of the plain of Peking that the Pan-shan rises in the same line of strike. This sunken area of Peking is thus open to the south-east towards the great plain, and bounded on the north-west by the flexure of Nankou; it is in fact an inbreak between Hong-shan and Pan-shan.

Nearly six degrees of latitude south of Peking lies Hsi-ngan-fu, and

greisen, and quartzite; Notes on the Geology of the Corean Archipelago, Nature, March 3, 1881, pp. 417, 418.

south of this great town rise the snow-covered peaks of the mighty *Tsin-ling-shan*, which trends in a straight line from W. 12° N. to E. 12° S. and marks the boundary between north and south China. It is a long range of unilateral structure; on its north side the gneiss reaches a height of over 11,000 feet; the more recent sediments lie to the south. In the east, on the road between Kai-fong-fu and Hsiang-yang-fu, it is completely faulted down across the strike; beyond this line it again emerges as the Hwai mountains, and attains a height of 4,000 feet. The last outposts may be seen near Nan-king, in the region at the mouth of the Yang-tse-kiang.

The rectilinear east-south-east trend of the Tsin-ling-shan and its prolongations thus differs considerably from the east-north-easterly or north-easterly strike of the Peking district. But before speaking of this great range reference must be made to some regions situated to the north of it.

The Wei-ho follows in its upper course the east-south-east trend of the Tsin-ling-shan and flows along the north foot of these mountains. A little above Hsi-ngan-fu, however, it abandons both this direction and the foot of the mountains and turns to the east-north-east; it thus reaches near Tung-hwan-ting the Yellow river, which here turns in a sharp elbow and then continues the direction of the Wei-ho up to the eastern termination of the mountains. In the triangular space confined between the river valley running to the east-north-east and the Tsin-ling-shan trending to the east-south-east other ridges rise which in an orographical sense form the northern outposts of the Tsin-ling-shan. Of these chains we must first separate off Hwa-shan, which trends in a different direction, and is situated close to the confluence of the Wei-ho with the Hwang-ho; we shall refer to this later. The other ranges, chief among which are Fu-niu-shan near the base of the triangle and Sung-shan near its northern apex, also follow an east-south-east direction, but their structure is not determined like that of the Tsin-ling-shan by folding, but by parallel fractures. We have here, indeed, the fragments of an ancient table-land formed of Cambrian sediments with directly superposed Coal-measures, but without the Carboniferous limestone, elsewhere so widely distributed. The transgressive Coal-measures are thus situated behind the Tsin-ling-shan, folded to the south, very much in the same way as the Coal-measures of Bohemia lie behind the Variscan chains, folded to the north.

The Tsin-ling-shan has been crossed in various places by David [1], Richthofen, Széchényi, and Lóczi. The transverse section of which we have the most precise knowledge is that on the Tsin-ling road which leads from the north into the basin of Han-tshung-fu; it has been described in detail by Richthofen. The northern slope is steep, the southern likewise,

[1] A. David, Journal de mon troisième voyage d'exploration dans l'Empire chinois, 2 vols., 8vo, Paris, 1875.

and the range thus resembles a solid beam; nevertheless, situated almost in the middle of this well-defined orographic region, lies an important tectonic boundary. Richthofen coming from the north first encountered a great band of gneiss accompanied by red granite, then Azoic schists and massive rocks, the Wutai-beds, and with these, rocks containing chlorite and hornblende. On this zone, patches of Carboniferous beds with anthracite are superposed in transgression, as is so often the case in the older folded ranges of Europe. The Wutai zone is followed on the south by folded beds, among which middle Silurian, upper Silurian, Devonian, and Carboniferous limestone may be recognized by their fossils. The first three members of this series are, as we have already stated, unknown in the whole of the vast region extending north of Tsin-ling-shan into Mongolia, where the Carboniferous limestone always rests directly on Cambrian beds; and it is very remarkable to observe that here, as in the Alps, the Andes, and so many other mountain ranges, the series of marine deposits becomes complete as it leaves the table-land to enter the great folded chains.

South of this folded zone a more recent granite mass emerges near Liu-pa-ting. It is situated south of the middle of the range. A band of micaceous slate and sericite phyllites, perhaps altered Carboniferous, follows the mountains with a completely abnormal strike; we then reach a zone, twenty-two geographical miles broad, occupying a third of the whole breadth of the chain, and with a completely different strike; from the north border of the mountains up to the granite of Liu-pa-ting the direction E. 12° S., or the normal direction of the Tsin-ling-shan, prevails, but in this broad zone the strike is to the east-north-east. We have now reached the region of the Sinian direction of folding; in Sze-tshwan it becomes north-east and dominates the whole of south China.

The rock with the Sinian strike which forms the broad zone on the south side of the Tsin-ling-shan is formed of micaceous gneiss, intensely folded with frequently repeated intercalations of crystalline limestone; perhaps, as Richthofen conjectures, Silurian sediments which have suffered metamorphosis.

Before discussing the adjacent folded ranges of south China, let us return once more to the north.

We have seen how the grill of Peking breaks off to the west against the plains of Ta-tung-fu and Hsin-tshou; the Hsi-tshou-shan forms its south-western extremity. From the border of this mountain fragment down to the Hwang-ho, a steep cliff, which forms the western boundary of the plain, runs past Pau-ting-fu and Tshöng-ting-fu. From Pau-ting-fu its direction is south-south-west, and further to the south before reaching the Hwang-ho it bends in a curve from south-south-west to south-west and west-south-west. This cliff, about 2,000 feet high, bears for its whole length the name *Tai-hang-shan*. In the north, near Tshöng-ting-fu, an

older mountain segment is visible; with this exception Tai-hang-shan forms the border of a vast table-land of Carboniferous sediments which extend from the north with horizontal bedding through the whole of southern Shansi and northern Shensi as far as the north foot of the Tsin-ling-shan. A first stage, which consists of Carboniferous limestone and coal-bearing sediments, is followed by a second formed of a supra-Carboniferous sandstone, and thus the table-land attains a height of 5,000 feet. On the east and south-east it descends in steps to the great plain, and Tai-hang-shan itself is partly a flexure and partly a step fault.

The way in which the southern part of Tai-hang-shan is bent backwards is very striking, and strange to say this course is repeated in a long narrow range formed of gneiss and other ancient rocks which emerges from the Carboniferous plateau. This range bears successively the names Hwa-shan (south of the Hwang-ho), Fong-tiau-shan, Hsian-mieu-shan, and Ho-shan. I should not be averse, while awaiting further information, to regard this whole range as a horst left in relief amid the broad sunken table-land. Beyond it flexures and faults running in the same direction follow one another up to the plain of Ta-tung-fu. This is succeeded on the west by a table-land presenting the same structure formed of a Mesozoic coal series.

Orographic blocks let down in steps thus surround the great plain on the whole of its northern side. The flexure of Nan-kou above Peking and Tai-hang-shan, the boundary face of the table-land, are the features most characteristic of this structure.

In the south the case is entirely different. We have already become acquainted with the Tsin-ling-shan as an asymmetric range folded to the south, like all the great chains of Asia, and we have already pointed out that other folds join on to its south side which strike to the east-north-east and further south to the north-east. The micaceous gneiss with crystalline limestone, which we mentioned as occurring on the south side of the Tsin-ling-shan, is followed south of the depression of Han-tshung-fu by a zone of folds formed of Silurian, Devonian, and Carboniferous limestone, and inverted to the south; these folds are covered towards the south by a series of sediments lying unconformably. This new series begins with limestone of unknown age; upon it rest coal-measures of the lower Jurassic; these are covered by red, argillaceous, and sandy sediments, most likely of lower Jurassic age, which fill the 'red basin' of Sze-tshwan. This more recent series has also experienced lateral movement and longitudinal fracture.

The folds which meet the southern slope of the Tsin-ling-shan are continued, as we have said, through the whole of the south of China. For a distance of almost ten degrees of latitude, says Richthofen, the numerous parallel and closely crowded mountain ranges striking from west-south-west to east-north-east are cut off transversely or diagonally by

the curve of the coast. We have seen that the same direction of folding also prevails in Tongking [1].

As regards the relations of China with the island arcs, the following must be borne in mind.

In the neighbourhood of Nan-king the continuation of Tsin-ling-shan reaches the sea. North of this point the whole country consists of ancient table-land; beneath it, pre-Cambrian folding of the Archaean and Azoic rocks, with a north-easterly strike, may be observed in places. The only marine deposits which have been recognized are those of the Cambrian system and the Carboniferous limestone. The Tsin-ling-shan does not correspond in its course with the island arcs. To the south of it lie chains folded to the south in which middle and upper Silurian as well as Devonian are known, but no recent marine deposits on this side of Yunnan. The strike of the chains certainly coincides with that of south Japan, and here, according to Naumann, we must look for the continuation of the arc of that island [2].

12. *The north-east of Asia.* In Europe the recurrence of folding directed to the north, from the pre-Devonian overthrusts of north Scotland to the most recent movements of the Alps, has shown how extraordinarily constant in direction the tangential movement may be over an extensive area; China affords a similar example.

The pre-Cambrian folds of northern China, which were worn down and then covered by the flat-lying Cambrian sediments, present the same north-east strike as prevails in that vast region of far more recent folding which extends south of the Tsin-ling-shan down to Tongking.

This same north-easterly direction, characteristic of the Sinian system of Pumpelly, also prevails with certain deviations to the north-north-east, in the whole of north-eastern Asia from the Great Wall to the Arctic Ocean. A study of the relations of this east Asiatic ridge trending to north-east and north-north-east with the Altai and the chains of Thian-shan, would require first of all a discussion of the extensive and laborious investigations which have been carried out by Russian geologists in the region of lake Baikal; but such a discussion would lead us too far from the subject of this chapter, which is devoted to the outline of the Pacific Ocean, and it must, therefore, be reserved for a later page. For the present it will suffice to mention some of the principal features.

Even in Liau-hsi some indications, as in the Y-wu-lu-shan, point to the occurrence of a strike directed to the north-north-east, but it is precisely

[1] Richthofen, Führer für Forschungsreisende, 8vo, Berlin, 1886, p. 309, 310.

[2] Tshe-kiang and Fu-kiang are still unfortunately almost unknown; Basset-Smith encountered granitic and felsitic rocks and steeply upturned schists on the islands of this coast; see Notes on the Geology of part of the Eastern Coast of China, Nature, June 16, 1887, pp. 163, 164.

here that observations become less connected. A fact of greater importance is the existence of a zone of volcanic rocks running from south-south-west to north-north-east, which Richthofen has traced from Wei-hsien in Shantung, past Tong-tshou-fu and the Miau-tau islands, through the valley of the Liau; and he believes it may extend into the neighbourhood of Mergen[1]. Richthofen also points out that the Great Khingan is not a mountain chain but the edge of a table-land, and that it nearly coincides with the prolongation of the edge of the Carboniferous table-land of Shansi, i. e. to the Tai-hang-shan[2].

If from Peking we cross the eastern Gobi by the route described by Muschketow, to the north-north-west, we encounter beyond the desert, on the right bank of the Sselenga, a grill of parallel chains which strike from south-south-west to north-north-east[3]. Wenjukow enumerates ten parallel chains besides the long range of the Apple mountains or Jablonowyi[4]. The Jablonowyi ridge represents, like the Khingan, the steep face of a flexure dropped on the east, or a fracture; this is confirmed by all descriptions of the road from lake Baikal to Tshita, and by Kropotkin's express statement. Here begins the great ridge of the divide, the *Stanovoi*, explored by Middendorf; it is a plateau of variable breadth surmounted by secondary hill ranges; its east border trends to north-east or north-north-east across the valley of Amur to the sea of Okhotsk, of which it forms the west shore, and is then continued to the Arctic Ocean. On the east it is followed by successive chains, all striking to north-east or north-north-east; among them, in particular, Dousse Alin, or Middendorf's Bureja mountains, and Sikhota-Alin, the coast range of Manchuria. Kropotkin has published an extremely instructive sketch-map of the trend-lines of these chains, which exhibit throughout a certain tendency to converge towards the southern half of the sea of Okhotsk, and all disappear along the south coast of this sea[5]. Hence the great number of islands and bays on this part of the coast, which is a true rias coast, like that of the south-east of China. In one of these bays, the bay of Tugur, west of the island of Klein-Shantar, Middendorf discovered on cape Karaulnoi, in Mamga harbour, contorted beds of clay slate, containing the first specimens of

[1] Richthofen, China, II, p. 50 et passim. The volcano Pei-shan at the sources of the Sungari appears to lie somewhat east of this line; cf. Proc. Geogr. Soc., London, 1886, VIII, p. 779. Richthofen refers here to the eruption of Ujun-Choldongi of 1721 to 1722 mentioned by Wenjukow; this region lies twenty-five versts SE. of Mergen on the river Nemer, not far from the mountain Dousse-Alin to be mentioned directly.

[2] Richthofen, op. cit., II, p. 520 et passim.

[3] J. Muschketow, Geologische Notizen über die Ost-Mongolei; Gornoi Journ., 1881, II, pp. 80–98, with a geological map of the route from Dolon-nor to lake Tarei.

[4] Wenjukow, Die russisch-asiatischen Grenzlande; German translation by Krahmer, 8vo, Leipzig, 1874, p. 187.

[5] Kropotkin in E. Récluz, Nouvelle Géographie universelle, VI, 8vo, Paris, 1861, p. 813.

Pseudomonotis Ochotica, which proves that the Trias was involved in the elevation of these chains. This fossil has acquired, as we shall see later, a peculiar importance in the history of the whole Pacific Ocean [1].

The furrow of lake Chanka, the Ussuri, and the lower Amur, as seen on the map, correspond very nearly with the west border of the coast range of Sikhota-Alin, and Récluz, in his description of this region, based on the observations of Kropotkin, makes the just remark that a slight submergence would suffice to convert Sikhota-Alin into a new island arc [2].

A comparison of Richthofen's results in northern China with those of Russian geologists in east Siberia thus enables us to recognize the Tai-pai-shan in Shansi, the Great Khingan in Mongolia, the Apple mountains in the trans-Baikal region, and the east of part of the dividing ridge of Stanovoi from the Apple mountains to beyond Okhotsk, as the edges of great platforms which have been let down in the direction of the Pacific Ocean. 'Certain facts,' says Richthofen, 'indicate that the Pacific basin is surrounded by step faults on the grandest scale [3].'

In front of these tectonic lines lie the extremely ancient fragments of table-land which surround the Yellow sea; in front of these again, lie the island arcs. We may now attempt to compare these arcs more closely with the mainland.

The origin of the Liu-Kiu arc cannot be discussed until the structure of Formosa is known in greater detail.

The arc of south Japan is connected, in Naumann's opinion, with the northern part of the rias coast of south China. This arc curves past the fragments of table-land surrounding the Yellow sea, and is joined in a peculiar syntaxis by the arc of north Japan.

Next, however, so far as we can judge at present, the arc of the middle part of Yezo, which we may suppose to represent a part of the arc of Sakhalin, arises outside the arc of north Japan, so that the latter is inserted, so to speak, between the coast chain and the arc in front of it. Still further towards the exterior lies the arc of the Kuriles together with east Kamchatka; towards the interior, on the other hand, the fragment of west Kamchatka.

We cannot say that these arcs are syntactic in a deep re-entrant angle, like the Asiatic chains on the Jehlam, or like the Armorican and Variscan mountains between Douai and Valenciennes, or like the Ural and the arc of Nova Zembla on the Konstantinov-Kamen. The only exception is the sharp syntaxis in the middle of Honshiu; here the bend is really similar to that of the above examples, yet there is a difference owing to the

[1] G. von Helmersen in A. T. von Middendorf's Reise in den äussersten Norden und Osten Sibiriens, I, 4to, St. Petersburg, 1848, p. 219, Atlas, pl. xvii.

[2] E. Récluz, Nouvelle Géographie universelle, VI, 8vo, Paris, 1861, p. 860.

[3] Richthofen, Führer für Forschungsreisende, p. 605.

approach of the Shichi-to chain, and the north Japanese arc reproduces so exactly the arc of south Japan in its main feature, that we are reminded of the conditions on the strait of Ormuzd where a secondary notching of a similar kind appears to be present (I, p. 426).

The island arcs lie against and behind each other at an obtuse angle, and this is the more striking since the succeeding arc of the Aleutian isles shows a far greater independence, and as we proceed in the direction of America we recognize a much greater contrast to the arcs, and a greater resemblance with normal syntaxis.

Apart from the Philippines, the relations of which are still unexplained, these arcs are seen to stand in very intimate connexion with the arcs of the Asiatic continent. Asia consists of an obstructive fragment of Indo-Africa—the peninsula of India, which does not now concern us, and of a great piece of the earth's crust folded to the south. The folds, however, are interrupted and separated by platforms which lie between them like rigid blocks, although in the platforms themselves we may also recognize the traces of much older folding in the same direction.

We shall show later, with greater detail than we have yet done, that the Himálaya actually terminates on the Brahmaputra. There are chains lying behind the Himálaya joining the meridional chains of Yunnan which pass the end of the Himálaya and are continued in the Malay arc. This arc we have traced through the Banda islands as far as the coast of New Guinea. But although to the south it passes considerably beyond the equator, yet in a tectonic sense it lies wholly behind the Himálaya, or if we were to number the great folded ranges from the exterior inwards, the Himálaya would receive the number 1 and the Malay arc the number 2. The encounter of the two ranges above the wedge-shaped fragment of Shillong is thus different from the syntaxis on the Jehlam.

We have already observed that our insufficient knowledge of Formosa prevents us from forming an opinion as to the arc of Liu-Kiu, but the south Japanese arc probably issues from the folds of south China, exactly as the Malay arc does from the chains of Yunnan, and it lies *behind* the Malay arc in the same sense as this lies *behind* or *within* the Himálaya.

In the same sense the chains of east Siberia lie behind or within those of south China, and, notwithstanding the peculiar insertion of the north end of the north Japanese arc in Yezo mentioned above, we must regard all those arcs which stand in relation to the east Siberian chains as lying further towards the interior. With regard to this point the absence of a more detailed knowledge of Sakhalin and of central Yezo is much to be regretted, for the map shows a much more exact correspondence of the coast range Sikhota-Alin with the distant arc of the Kuriles than with the arc of Sakhalin lying between them.

Thus the east Asiatic coast does not resemble a series of independent

ranges advancing towards the sea, but rather a *stupendous virgation extending over the whole breadth of Eurasia*, the successive divergence of the same folded systems which, closely crowded together in the interior of the continents, form the great and lofty highlands. In this divergence each of the great branches shows near its extremity, i. e. towards the Ocean, a tendency to recurve to the north, and thus arise the island festoons of east Asia.

13. *The arc of the Aleutian islands.* In scarcely any other part of the Pacific outline is the tendency towards the arc-like disposition so sharply expressed as in the zone of volcanos and mountain fragments which proceeds from the Commander's islands through the Aleutian islands, the peninsula of Alaska, Kadiak and Kenaï, and separates Behring sea from the Ocean. Grewingk, in 1850, published a geological description and map of this region, based on the observations of his time, which may still be consulted with advantage; he compared it to a knotted rope hung between the rocky pillars of America and Asia, which, sinking under its own weight, had bent its supports towards one another[1]. Grewingk represented the contrast between the Aleutian and the American directions of strike by means of trend-lines, and Dall's subsequent investigations appear to indicate that between the Mackenzie and the upper Yukon, in about lat. 64° N., the Aleutian and the west American chains meet in syntaxis at a fairly acute angle[2]. The chain running to the north-east which reaches this part of the syntaxis is called by Grewingk the Tschigmitgebirge; Dall terms it the Alaskan range. It lies on the interior side of the principal range, which extends from the north coast of Cook's inlet through Alaska and the island arc. Cook's inlet itself and the strait of Shelechov lie in the strike of the mountains, somewhat like the gulf of Ancud and the channel of Moraleda in the south of Chili. The gulf of Tshagatska (Prince William sound) and the mouth of the Copper river mark the place where the course of the coast is determined by the re-entrant angle of syntaxis. Whether the Romanzov mountains in the north between fort Yukon and the Arctic Ocean, or the upturned Palaeozoic beds which Beechey observed near cape Lisburn, must be regarded as northern ranges parallel to the Aleutian arc can hardly be determined at present.

[1] C. Grewingk, Beiträge zur Kenntniss der orographischen und geognostischen Beschaffenheit der NW.-Küste Amerikas mit den anliegenden Inseln, in Verh. Min. Ges., St. Petersburg, 1850, 8vo, p. 215; E. von Eichwald, Geognostisch-paläontologische Bemerkungen über die Halbinsel Mangischlak und die Alëutischen Inseln, 8vo, St. Petersburg, 1871.

[2] W. H. Dall, Alaska and its Resources, 8vo, Boston, 1870, p. 286; cf. further, Amer. Journ., 1868, 2nd ser., XLV, pp. 96–99, and 1876, 3rd ser., XI, p. 242; C. A. White, On a small Collection of Mesozoic Fossils collected in Alaska by Mr. Dall, Bull. U.S. Geol. Surv. Territories, 1884, No. 4, pp. 98–103; for the Yukon, also Krause, Zeitschr. Erdk., Berlin, 1883, XVIII, p. 348; Schwatka, Journ. Amer. Geogr. Soc., 1884, XVI, p. 374 et passim.

The breaking up of the mountain chain which is accomplished by the isolated advance of the peninsula of Alaska, and then by the division of the prolongation of the peninsula into the groups of islands, is a fresh example of a phenomenon which we have observed from Kamchatka to the Kuriles, from Arakan to the Nicobars, and on other coasts having the Pacific structure. Here, however, the orographic form of the peninsula is modified by a form of erosion peculiar to the north. This is represented by extremely deep transverse valleys, which in Norway are called 'eyde,' in Alaska 'perenossi,' i. e. carrying places or 'portages' as they are called in Canada, though this last term is used in a more extended sense to include the low watersheds of the abraded Archaean shield. They are the same deep valleys as are described by Boas on Cumberland peninsula, where they connect the corresponding fjords of the two coasts (II, p. 32). Alaska, just like Cumberland peninsula, is cut across many times by these deep furrows. The first runs from the most northerly part of the peninsula through the great lake of Iliamna, and Grewingk enumerates five other perenossi; lakes frequently lie in their course, and Dall was informed that some of them are so low that in the whole transit it is scarcely necessary to lift the boat out of the water.

Archaean rocks are known on the south-east coast of Kenaï and Kadiak, as well as at several localities in Alaska; at Unalashka and in some of the western islands as far as Attu, metamorphic rocks and ancient porphyry are mentioned as forming the foundation. In the Commander's islands the foundation is Archaean. At cape Nunakhalkak, on the north-east coast of Alaska (about lat. 58° 20′ N.), Pinart found fossils of the Trias[1]; on the east coast Jurassic deposits are known, which, as it appears, belong to different stages of the middle and upper Jurassic, and the Aucella beds appear at various points on the east coast as well as near Port Möller on the north-west coast of the peninsula.

The Tertiary formation of this region deserves particular attention and renewed investigation. In many places, particularly in Cook's inlet, the Tertiary leaf-bearing beds with lignite occur which distinguish the Arctic regions in so peculiar a manner. Heer has described their flora[2]. They extend as far as cape Tolstoi in Morton sound. Above these leaf-bearing beds Dall observed, near Nulato, on the lower Yukon, a brown sandstone with Crepidula, Ostraea, and other marine mollusca of extinct species. This sandstone has a fairly wide extension. On the Shumagin islands, which lie off the south-east coast of Alaska, Dall found resting on syenite or granite, first very much altered quartzite, then blue sandy shales with beds of lignite, silicified wood, beds of conglomerate and leaves of Platanus,

[1] P. Fischer, Sur quelques fossiles de l'Alaska, in A. L. Pinart, Voyages à la Côte Nord-Ouest de l'Amérique, 4to, 1875, I, p. 32.

[2] O. Heer, Flora Fossila Alaskana, 4to, Stockholm, 1869 (in Svensk. Akad. Handl.).

then conglomerates and sand with Sequoia, and above this the brown marine sandstone with Crepidula, vertebrae of whales, oysters and wood perforated by borings. The Tertiary beds are traversed by basalts [1].

These deposits, which appear to be of middle Tertiary age, are so far the only trace of a connexion with the marine Tertiary beds which have been mentioned as occurring in Spitzbergen and the east of Greenland (II, pp. 69, 73). They must be carefully distinguished from other marine beds which contain living species or a fauna very closely allied to the present, and which are regarded by many observers as also of Tertiary age. These occur at many points of the Aleutian arc, as well as in Kamchatka, Sakhalin, and on the Pribylov islands, resting horizontally against the older rocks of the coast, and Grewingk has justly emphasized their striking resemblance to the shell-bearing beds of Beauport near Quebec in Canada.

In conclusion, a zone of mighty volcanos takes part in the structure of the Aleutian arc. It would be superfluous to enumerate them. With the giant Iliamna and the Ujakushatsh (or Burnt mountain) on the west side of Cook's inlet, this volcanic zone makes its entrance into the continent of America. It is very active; several great eruptions occurred in the course of the eighteenth century: during one of them, in 1796, the new volcano, Saint Johann Bogoslow, was formed, which rises from the sea west of the northern point of Unalashka; finally in December, 1883, the mouth of Cook's inlet was the scene of violent volcanic phenomena.

14. *The west coast of America.* The lofty mountain ranges which border the Pacific coast of America have been already described. The contrast between their direction and that of the Aleutian islands is very striking. In Chatham straits, east of Sitka, Blake observed mica-schist in an almost vertical position striking parallel to the coast [2], and from the works of Canadian geologists we have learnt that Vancouver and the Queen Charlotte islands must be regarded merely as the outer chains of those cordilleras which traverse the north-western part of America. Further to the south we reach the great lava flood of Washington and Oregon, beneath which only isolated fragments of the downthrown cordillera are visible. It is in the Cascade range that these eruptive products attain their greatest height; and the overwhelmed forests beneath the lava recall the similar occurrences of Tertiary age which are so widely distributed in high latitudes. This volcanic region extends as far as mount Shasta, and some observers include in it the range of Lassen's peak which joins the sierra Nevada.

We here approach the region of the Basin ranges, distinguished by its

[1] Dall, Note on Alaska Tertiary Deposits; Amer. Journ., 1882, 3rd ser., XXIV, p. 67.

[2] T. A. Blake, Topographical and Geological Features of the NW. Coast of America; Amer. Journ., 1868, 2nd ser., XLV, pp. 242–247.

peculiar structure. More or less meridional chains were formed by folding, then followed faults, which run almost with the strike of the folds, and along these the folded country has been let down. Diller has shown that the structure of the Basin ranges extends to the northern part of the sierra Nevada. This, too, is cut through between Sacramento and Honey lake by two faults running almost with the strike, which form American valley and Indian valley with a downthrow on the east, the dip being directed mainly to the west. On the west side of Honey lake lies a third line of fracture, which corresponds to the east border of the sierra. The outermost part of the west border of the mountains appears to be overturned [1].

The difference in structure between the Coast ranges and the sierra Nevada, indicated by earlier investigations, is shown by fresh observations to be less than was supposed. In the north, Diller has found fossils of the Carboniferous limestone west of Shasta valley in the region of the Coast ranges; and, further south, White has shown the correspondence of the Aucella beds of the Coast ranges with those of the sierra. Becker regards both mountain ranges as forming part of the system of western cordilleras. Since the lower Cretaceous, and very probably since a far earlier period, the whole region between the Wahsatch and the Pacific coast has, according to Becker, been the scene of the 'recurrent, if not constant action of lateral compression, exercised practically in one and the same direction [2].'

The distinction between the movement of folding and the formation of great fractures along which collapse takes place is becoming recognized with ever-increasing clearness. In the north, between the Siskiyou mountains and the Cascade range (south Oregon), the Cretaceous formation, according to Whitney, is upturned. On the western side of the sierra Nevada the upper Cretaceous lies horizontally in the foothills. In the Coast ranges the middle Tertiary beds have also been involved in the folding. The age of the folds, as far as the position of the beds gives evidence of it, thus differs locally. The faults and subsidences, it is true, are also of different age, but the way in which they intersect the folded bands leaves no room for doubt that they are younger than these. Most observers hold the view that they are very recent, and that even the movements taking place at the present day are a continuation of the great process of subsidence. Gilbert's observations on the more recent dislocations along the Wahsatch fault have already been mentioned (I, p. 578). It is asserted

[1] J. S. Diller, Notes on the Geology of North California; Bull. U.S. Geol. Surv. Territories, No. 33, 1886, pp. 373–387.

[2] G. F. Becker, Notes on the Stratigraphy of California, Bull. U.S. Geol. Surv. Territories, No. 19, Washington, 1885, p. 212; Cretaceous Metamorphic Rocks of California, Amer. Journ., 1886, 3rd ser., XXXI, pp. 348–357, &c.; for the palaeontological evidence of the Aucella beds, C. A. White, On the Mesozoic and Cainozoic Palaeontology of California, Bull. U.S. Geol. Surv. Territories, No. 15, 1885, pp. 7–32.

that the earthquake of March 26, 1872, on the east border of the sierra Nevada (I, p. 74) was accompanied by a dislocation, and Reyer describes ice-polished granite cliffs on lake Fordyce which have been cut through by post-glacial faults[1]. Within the downthrown area of the Basin ranges, and particularly in the northern part of south Oregon, Russell has traced fresh indications of quite recent movements, not yet covered by vegetation, and extending for great distances along ancient fault-lines. They traverse recent terraces and cones of débris, and may attain a throw of fifty feet; Russell thinks that some of them have been produced within the last few years, and he gives instances from Surprise valley (long. 120° W., lat. 41°–42° N.), which is often visited by earthquakes[2].

In Central America the cordillera of the Antilles is broken off towards the Pacific Ocean (I, p. 542).

Through the whole of South America as far as cape Horn, the course of the coast, as we have already seen, is determined by the mountain chains.

[1] E. Reyer, Zwei Profile durch die Sierra Nevada; N. Jahrb. Min., Supplement, IV, 1886, pp. 291–326, map.

[2] I. C. Russell, A Geological Reconnoissance in South Oregon; IV Report of the Ann. Rep. U. S. Geol. Surv., 1882–1883, 8vo, 1884, pp. 431–464, in particular pp. 442 et seq. The attempts made to draw definite conclusions as to the persistence of tectonic movements from the behaviour of rivers do not seem to me at present to have led to convincing results, for the question is affected by displacements of the strand-line, which must be regarded as independent of these tectonic movements; cf. J. le Conte, A Post-Tertiary Elevation of the South Nevada shown by the River-beds, Amer. Journ., 1886, 3rd ser., XXXII, pp. 167–181.

CHAPTER IV

COMPARISON OF THE ATLANTIC AND PACIFIC OUTLINES

The Atlantic structure. The Pacific structure. Their dissimilarity. Distribution of islands and volcanos. Overthrusting of the depressions. Progressive completion of the Mesozoic series towards the Pacific coast.

THE contents of the two preceding chapters have now placed us in a position to appreciate more precisely the distinction which exists between the Atlantic and Pacific coasts.

Let us first recall the strange approach to a symmetrical arrangement which manifests itself in the *Atlantic region.*

In the north stands the wedge-like mass of Greenland; on each side of it lies an arm of the sea. On the west the mainland begins with an imposing range of very ancient gneiss, which borders the west coast of Baffin bay and Davis strait, and extends nearly as far as the strait of Belle Isle. On the east a similar chain of gneiss forms the greater part of the islands and coasts of northern Norway; it appears to find its continuation in the gneiss of the outer Hebrides.

Within the Hebrides follow the pre-Devonian overthrust folds of the Caledonian chain; I know of nothing similar in America.

We now encounter in the west the Canadian shield with its flat bedding, and the shallow pan of Hudson bay surrounded by a girdle of glint lakes. In the east we have the Baltic shield, with the Palaeozoic beds lying equally flat upon abraded Archaean folds, and the shallow Baltic pan likewise surrounded by a girdle of glint lakes. It is only by regarding certain flat-bedded patches as representing the border of the Canadian shield, that it can be said to reach the open Ocean at all, and then it forms only a very short stretch of coast along the strait of Belle Isle. The Baltic shield is nowhere in contact with the Atlantic Ocean, properly so called. On the other hand both shields reach the Arctic Ocean; Coronation gulf in the west, the Varanger fjord in the east, and to a certain extent also the gulf of Onega, present the characters of glint bays.

Beyond the strait of Belle Isle follow the jagged rias coasts of Newfoundland, New Brunswick, and Nova Scotia, where the folds of the mountain ranges which were elevated towards the end of the Carboniferous period sink beneath the sea. These mountain ranges are folded to the

north-west and north, and their outer border coincides with the right bank of the lower St. Lawrence and the east shore of Belle Isle strait. The gulf of St. Lawrence forms the boundary of these folded ranges; the island of Anticosti does not belong to them, but to the border of the shield. To this rias coast corresponds in Europe the rias coast of the Armorican range, which is also in its main features post-Carboniferous, certainly pre-Permian in age, and which extends from the Shannon nearly to La Rochelle. This range is cut through by St. George's channel and the English channel; it is folded to the north-east, north, and finally to the north-north-west.

In Europe the next part of the Atlantic coast further south is occupied by the last outposts of the Pyrenees; we may regard the formation of this chain, together with the Alps, as subsequent for the most part to the subsidence of the pre-Permian ranges, the course of both being to a large extent determined by the trend of those older mountains and by the position of their faulted margins.

The overthrusting of the northern border appears to be less marked than in other European ranges; towards the west, in the north of Spain, this border reaches the sea, but it has collapsed in the Basque provinces (I, p. 289; II, p. 121). Then comes, along the north-west coast of Spain, the fractured margin of that group of structures, almost unique in their arrangement, which form the basin of Asturias, and indeed in such a manner that the several members of this basin become more and more perpendicular to the coast as they strike out to sea. This basin also is of pre-Permian age, and it looks as if it were about to repeat itself in the sudden bend of the Betic cordillera in the straits of Gibraltar.

It is the fragmentation and reconstruction of the folded ranges which have given to the coast of western Europe its variety of form. These processes did not occur in North America, and there a mediterranean sea bounded towards the Ocean by the arc of the Antilles lies much further south than in Europe. In Europe the arc of the Antilles finds its precise homologue in the arc of the Betic cordillera.

The Alleghanies and all the other folded ranges of eastern North America as far as Newfoundland are folded away from the Atlantic Ocean and turn their inner side and their oldest rocks to it. Our increasing knowledge of the mountains of Brazil shows us more and more clearly that the folding in all the chains of this region is also turned away from the Atlantic in the direction of the Andes, so that the innermost zones lie next this Ocean. Consequently the arc strikes out to sea in cape Corrientes and Staten island.

In west Africa the end of the great Atlas is unknown; the south shows fractured table-land.

With the exception of the cordillera of the Antilles and the mountain

fragment of Gibraltar, which form respectively the boundary of the two mediterranean seas, the outer side of a folded range nowhere determines the outline of the Atlantic Ocean. The older folded ranges which extend from Maine to Newfoundland turn, it is true, their outer side to the lower St. Lawrence and the strait of Belle Isle, but where they reach the great Ocean they disappear beneath it. *The inner sides of folded ranges, jagged rias coasts which indicate the subsidence of mountain chains, fractured margins of horsts, and fractured table-land form the diversified boundary of the Atlantic Ocean.*

The same structure also characterizes the coast of the Indian Ocean as far to the east as the mouths of the Ganges, where the outer border of the Eurasian chains meets the sea. The Erythraean trough, the fracture of the Quathlamba in Natal, as well as that of the Sahyádri in India, and the structure of Madagascar, the faults of which have been recently described by Cortese, indicate that the structure of this region has been determined by tabular fractures[1]. It is only in the Persian gulf that some of the outer Iranian zones reach the sea.

The west coast of Australia likewise exhibits Atlantic structure. From the arrangement of the folded ranges we know that they turn their convex side to the Pacific Ocean, and a comparison with South America shows that from the continent of Australia as far as New Zealand and probably New Caledonia, a more or less concentric system of folds is present, turned towards the Pacific side.

The west coast of Australia thus presents much the same relations as that of the east coast of Brazil.

The borders of the Pacific Ocean may be divided for convenience into five parts.

The first is formed by the *arc of the Aleutian islands.* While the north of the Atlantic Ocean is characterized by the Archaean mass of Greenland, here on the other hand is swung an island arc, affording with its folded Mesozoic beds and its inner zone of active volcanos a complete contrast of structure. The syntactic angles of the arcs in the north Pacific Ocean at once recall the relations of the mountain chains of India (I, p. 462).

The second part consists of the *west coast of North America,* from the gulf of Kenaï down to the coast of Mexico. The Queen Charlotte islands are regarded by Canadian geologists as an outer chain of the cordilleras.

The third part is *South America*; it begins in Guatemala, where the cordillera of the Antilles strikes across Central America, is divided into two by a syntaxis in the gulf of Arica and prolonged in an arc to the south beyond cape Horn. This part is characterized by the coast cordillera,

[1] E. Cortese, Una escursione al Madagascar, Boll. R. Com. Geol. d'Italia, 1887, XVIII, pp. 129-134; and Osservazioni geognostiche sul Madagascar, tom. cit., pp. 181-191.

where the stratified series does not appear to begin till the Neocomian; it recalls in many respects the coast chains of California, as well as the Nicobars and Andamans, which have a similar structure.

The fourth part is formed by the *arcs of eastern Asia*, which we have recognized in many of their most important segments as the recurved extremities of the great chains of central Asia; they are not syntactic after the manner of independent arcs, but lie one behind the other, forming the termination of a series of chains folded in the same direction and belonging to a single system. The great Malay arc marks the southern border of this system. Timor and Soemba lie outside it; whether these two islands should be included in the Australian region must for the present remain undecided.

As the fifth part we regard the *Australian chains* together with New Zealand and New Caledonia. An opportunity has already presented itself of comparing the Australian chains of the Flinders and Adelaide ranges as far as the east coast with the meridional sierras in the west of Cordova. The absence of middle Tertiary deposits over the whole of the eastern coast of Australia and Van Diemen's Land, in contrast to their rich development on the south coast of Australia and in Bass strait, leads to the supposition that the continent east of the existing coast has only in comparatively recent times subsided to the great depths which are now known to occur in this region.

To complete the boundary of the Pacific Ocean we should here add, perhaps, a south part, the *Antarctic*, but the accounts at our disposal of this region are too fragmentary to be of any value. The syntaxis of an arc lying outside the Australian system with the south side of New Zealand (II, p. 183, Fig. 16) is not without suggestiveness. In the more southern latitudes, H. Reiter has concluded from the observations of travellers, that the regions corresponding to the Pacific Ocean and those lying further to the east, from the Balleny islands and Victoria land to the south Orkneys, are constructed on the Pacific type; the other regions, however, on the Atlantic type[1]. It is possible that this conjecture may be confirmed some day by fresh discoveries.

With the exception of a part of the coast of central America in Guatemala, where the bending cordillera of the Antilles has sunk in, the whole border of the Pacific Ocean, wherever it is known in any detail, is formed of mountain chains folded towards the Ocean in such a manner that their outer folds either form the boundary of the mainland itself or lie in front of it as peninsulas and island chains.

No folded range turns its inner side to the Pacific; no table-land reaches the shores of this Ocean.

[1] H. Reiter, Die Südpolarfrage und ihre Bedeutung für die genetische Gliederung der Erdoberfläche, 8vo, Weimar, 1886, 34 pp., map.

In the *Atlantic region* the shallow basin of Hudson bay on the Canadian shield corresponds to that of the Baltic and the gulf of Bothnia on the Scandinavian shield. The irregular arms of the sea around the gulf of St. Lawrence, between the rias coasts of the ancient mountain folds of New Brunswick, cape Breton, and Newfoundland, occupy a position similar to that of the English channel which crosses the Armorican folds. The great inbreak of the foreland of the Antilles occupied by the gulf of Mexico finds no counterpart in the European region, where a dominant character is the repeated formation of mountain chains; the Caribbean sea represents the Mediterranean, unless, indeed, we prefer to compare it with the basin of Asturias.

The volcanic islands stand in groups, like the Azores, the Canary islands, and the Cape de Verde islands, or run in straight lines as in the prolongation of the Cameroons in the gulf of Guinea. The coral reefs of the Laccadives and Maladives, as far as the Chagos islands, also lie in a straight line. Volcanos arranged in curved lines only occur in one of the two regions in which the Pacific type encroaches on the Atlantic region, namely in the Antilles.

Kerguelen, according to the investigations of Studer, Moseley, and Renard, consists of successive sheets of lava, chiefly basic[1]. These rise in great terraces one above the other; the trachytes and phonolites appear to be older than the basalts. Between the basic flows there exist in some places intercalated beds of lignite, sometimes with trunks of great conifers, probably the relics of ancient forests. These facts show that Kerguelen is the remains of a once more extensive land and that the outflows did not take place beneath the sea. This resemblance with the Faeröe islands and Iceland is very remarkable.

In the *Pacific region*, on the other hand, and particularly in that part of it which belongs to Eurasia, the arc-like disposition and the 'hinder seas' within the arcs are characteristic. We may doubtless regard that branch of the Mediterranean which lies to the north of Candia and Cyprus as a representative of these hinder seas of eastern Asia; the gulf of Pegu is another example of this relation which recurs under various forms as far as Behring sea. It is less marked on the west coast of America. The boundaries of the strait lying on the inner side of Queen Charlotte islands are particularly incomplete. The gulf of California, on the prolongation of the valleys of San Joaquin and the Sacramento, as well as the gulf of Corcovado on the prolongation of the longitudinal valley of Chili—both of them clearly determined by the strike of the mountain chain—differ to

[1] T. Studer, Geologische Beobachtungen auf Kerguelenland, Zeitschr. deutsch. geol. Ges., 1878, XXX, pp. 327–350, map, pl. xv; H. N. Moseley, Notes of a Naturalist on the 'Challenger,' pp. 184–215; A. F. Renard, Notice sur la géologie de l'île de Kerguelen, Bull. Mus. R. d'Hist. nat. de Bruxelles, 1886, IV, pp. 223–272, pl. v.

some extent from the hinder seas of eastern Asia. They do not lie behind the cordilleras, but between the coast chain and the principal cordillera, or entirely within the coast chain, as happens in the south, and these peculiarities are repeated with slight modification in the strait of Shechelov and Kenaï sound.

The mountain arcs which characterize the boundaries of Eurasia, and in particular of eastern Asia, exhibit the arcuate plan in almost every possible stage of existence. Beginning with a completed cordillera with volcanos alined on its inner side, as in Italy—or upon its inner side and in the midst of the cordillera itself, as in north and south Japan—we pass to a cordillera cut off by the sea and prolonged by a mere chain of islands, with volcanos rising out of the sea, as in the chain of Pegu (coast of Arakan, Nicobars, and Andamans) with the volcanos of Puppa Doung, Chouk Talon, Barren island, and Narkondam, on the inner side; and then to an arc having no visible attachment to the mainland, with fragments of the cordillera forming an outer chain of islands and volcanic mountains an inner chain, as in the Liu-Kiu; next to a volcanic arc with the merest remnants of a cordillera, as in Java; and finally to a volcanic arc alone, as in the Kuriles, unless, indeed, the east of Kamchatka represents a part of the cordillera of these islands.

The case is similar as regards the outer Australian arcs. If we accept Dana's views as to the trend-lines of the Polynesian islands we must regard not only New Caledonia with the Lousiade group, but also the Loyalty islands and the whole zone of the New Hebrides, the Solomon islands, New Ireland, and the Admiralty group as outer arcs of the Australian region.

Whatever may be the true relation of this chain of islands to the mountain ranges of Australia, it is certain that in advancing towards the Ocean the arrangement of the islands becomes less and less arcuate. To the east, on the west coast of central America occurs, as we have seen, the only case in which a folded range is cut directly across by the Pacific coast. This is the cordillera of the Antilles, with its well-known resemblance to the cordilleras of South America. Precisely at that point where the arcuate continuation of this chain might be expected to meet the principal chains of South America, lie the volcanic Galapagos—a sporadic group presenting the same form of association as occurs elsewhere in the Atlantic region (I, p. 143).

We have quoted Richthofen's observation that 'certain facts point to step faults on the grandest scale as forming the boundary of the Pacific basin[1].' Drasche believed that it would be sound geology to draw the

[1] F. von Richthofen, Führer für Forschungsreisende, 8vo, Berlin, 1886, p. 605. We may remark in passing on the concordance in the results obtained by investigators in describing the continental margins; see C. Vélain, Les Volcans, 8vo, Paris, 1884, p. 126, figs. 42 and 43, and J. Walther, Über den Bau der Flexuren an den Grenzen der

western boundary of the Pacific Ocean outside the island arcs from Kamchatka through Japan and onwards from New Zealand through Auckland and Macquarie islands to Victoria land in the Antarctic region [1]. In any case we see how the volcanic circle of the Pacific resolves itself into a series of arcs. Many of these lie inside the fragmentary remains of a cordillera; others, especially the giant volcanos of South America, stand upon the cordilleras themselves. Further, we can now clearly recognize that the hypothesis of the formation of folded chains by the thrusting from the Ocean towards the land of the border of a sinking basin or geosynclinal is in no way founded on fact. There is no geosynclinal in the world greater than the Pacific, and the mountain ranges, so far from being turned away from it, are turned in the opposite direction, facing it, and so afford an example on the grandest scale of the general tendency to overthrust the depressions (I, p. 143).

The march of the folded ranges on the borders of the Pacific is accompanied both in North and South America by a general descent of the mainland in the opposite direction, that is towards the Atlantic, and on both continents almost the whole of the rainfall flows away on this side. The same is true, although not in so marked a manner, of the other continents. A. von Tillo has described the line which runs from cape Horn along the west coast of America to Behring strait, and from there through the middle of Asia across the coast of Syria east of the Nile to the cape of Good Hope, as 'the chief watershed of the globe [2].' When we include Arabia and India also in the region bounded by coast built on the Atlantic type we realize how disproportionately large is the volume of fresh water which it supplies to the sea.

A last important character should here find mention. This is *the completion of the marine Mesozoic series which we perceive as we approach the Pacific coasts.* On the Atlantic coasts nothing similar is to be observed. This fact, so important in the history of the Oceans, will clearly appear in the following chapters.

Kontinente, Zeitschr. Naturwiss., Neue Folge, Jena, 1886, XIII, Taf. xii, fig. 3. Walther lays particular stress on Scrope's view, that eruptions predominate in those parts where the convexity turns downwards.

[1] R. von Drasche, Über paläozoische Schichten auf Kamtschatka und Luzon; N. Jahrb. Min., 1879, pp. 265–269.

[2] A. von Tillo, Ein Wort über die Hauptwasserscheide der Erde; Peterm. Mitth., 1887, XXXIII, p. 101.

CHAPTER V

PALAEOZOIC SEAS

Introduction: The abyssal region; cycles; thickness of the sediments. The North Atlantic continent. Upper limit of the Silurian. Universality of the middle Devonian transgression. The Carboniferous system. Paralic beds. Alternation of coal beds and marine sediments. Transgression of the Carboniferous limestone. The Permian system. Gondwána land. General Survey.

THE object of the next three chapters is not to give a complete survey of the results of stratigraphical geology. From the earliest times the starting-point of all the various theories which relate to changes of land or sea has been the remarkable fact that we find in the midst of the land the remains of shells or fishes belonging to the sea. This was the problem which first pressed for solution; now another question confronts us, and we must seek to determine, by means of the facts ascertained in the study of strata, whether the conditions under which inundation and emergence took place in early times were of such a nature as to compel us to seek their explanation in secular oscillations of the continents, or whether, on the contrary, this hypothesis is incompetent to explain them. We are thus led to consider the successive changes in the extension of the seas, and at the same time the various nature of the sediments.

While dealing with the first point we shall have occasion to refer in greater detail to the fact mentioned at the conclusion of the last chapter —that the Mesozoic series grows more complete as we proceed from the interior of the continents towards the Pacific Ocean. In the second place, in treating of the Carboniferous period, the formation of the Coal-measures must be carefully discussed, for, in explanation of this, it has been assumed without hesitation that the solid land may have oscillated up and down as many as a dozen times, or even more. In our treatment of the Mesozoic æra and subsequent periods we must pay particular attention to the nature of the calcareous formations.

The treatment of the subject will consequently be very unequal, and only such facts will be chosen as have an important bearing on the question at issue.

A study of the history of the seas must certainly be based on a knowledge of their existing state. This knowledge, however, is very fragmentary. The expeditions undertaken in recent times to explore the deep regions of the ocean have brought to light so many new and

unexpected facts, that it is evident we have as yet scarcely crossed the threshold of great discoveries in this field of investigation. But these explorations are attended by every kind of difficulty; isolated soundings, separated by great intervals, are only obtained here and there. The slopes of our mountains, on the other hand, reveal to the eye, in innumerable exposures, vast masses of sediments accumulated at various depths in the ancient seas, together with the remains of the animals which peopled them.

Among these ancient formations we may distinguish those which have been deposited by evaporation from solution, such as gypsum and rock-salt; next clastic sediments, i. e. those which have been mechanically transported and then deposited on the bottom, such as sand and mud; and finally organic formations, such as coral reefs, which have been constructed by living creatures. In addition to these three chief groups, two others must also be mentioned. They both resemble clastic formations in many important respects, but their material is not derived from the solid land, which, as is generally admitted, is the source of clastic deposits, but from the depths of the sea itself. These are, first, volcanic ashes and scoriae, which rise from the bosom of the earth and spread themselves out over the floor of the ocean; and secondly, the remains of the hard parts of calcareous or siliceous organisms, such as Radiolaria and Globigerinae, which, together with fragments of shells and other débris, form a silt of organic origin, and these have contributed largely to the sediments of ancient seas, now forming a visible part of the earth's crust.

The chemical composition of beds of rock-salt and its associated minerals, shows that the substances held in solution by the sea were the same in the past as in the present. But as soon as we leave these products of evaporation, formed in lagoons or in more or less enclosed arms of the sea, and turn to the depths of the Ocean, the difficulties of comparison increase.

In existing seas the temperature remains constant from a certain depth, which diminishes towards the poles, down to the bottom. The sun does not penetrate into this abyssal region, the manifold influence of diurnal and seasonal changes or differences in latitude does not affect it. The same climate prevails in the depths of all the oceans, and a uniform fauna characterizes them, exposed to no change of conditions except differences of pressure, which correspond to differences of depth. Thus it appears, as recorded by Wyville Thomson, that the *Challenger* in dredging below 500 to 600 fathoms everywhere brought to the surface a fauna identical in all essential features, in the Indian Ocean as in the Southern Ocean down to the Antarctic circle; in the Pacific Ocean, both north and south; and in the different regions of the Atlantic Ocean [1].

[1] C. Wyville Thomson, Report on the Scientific Results of the Voyage of H.M.S. *Challenger*, during the years 1873–1876, under the command of Captain G. S. Nares and Captain F. T. Thomson; Zoology, I, London, 1880, pp. 43–50.

It is not until we reach the shallower zones of the sea that the differences in warmth and illumination begin to manifest themselves, the distinction of climates makes itself felt, and zoological provinces assume definite limits. The diversity in external conditions of existence increases as we approach the shore, and with it the multiplicity of living forms themselves; and beyond the margin of the tides, on the dry land, where the rays of the sun have only to penetrate the atmosphere, and where lungs have taken the place of gills, not only the variety but the variability of external conditions reaches its maximum. We can now more easily understand the extraordinarily wide distribution of certain marine faunas in early times; it is also comprehensible that on dry land and in the shallower zones of the sea the displacement or even the extinction of faunas may be brought about by altered conditions of existence. But this renders it all the more difficult to explain the fact that the cosmopolitan abyssal fauna, exposed to no difference of temperature and hardly even subject to change of place, should yet have likewise suffered transformations.

Thus the whole of the animal world which forms the biosphere falls into two chief groups, according to its habitat, of which one is under the influence of the sun, the other withdrawn from this influence. The first group comprises the inhabitants of the land, of fresh water, and of isolated zones of the sea; the second group is the abyssal circle of living things.

The absence of sunlight in any region inhabited by living beings, whether in a cave, or the depths of a lake, or the bottom of a well, or finally in the abysses of the Ocean, betrays its effects, in the most diverse classes of the animal kingdom, most obviously by modification or atrophy of the eye. A great number of animals in the abyssal regions are blind, so were many Trilobites of the lower Silurian, and particularly of the Cambrian seas—a correspondence which has been repeatedly pointed out; the phenomenon, however, is so peculiar that it deserves to be illustrated by a few examples.

A little blind Arthropod, *Cecidotaea stygia*, which lives in the caves of North America, is closely related to *Asellus communis*, which possesses sight and does not inhabit caves; it looks like an emaciated, badly armed Asellus which has lost its eyes. Its introduction into the caves must be later than the time when the river terraces were being formed in the valleys of the United States. But it has been shown by Packard that the optic nerve, together with the ganglia, is completely absent in all the specimens of Cecidotaea which he has examined; nevertheless, in some individuals a small dark spot is visible on the exterior, which under the microscope is seen to represent the extremely rudimentary remains of the eye. In the majority of individuals, however, there is no trace of such a structure [1].

[1] A. S. Packard, On the Structure of the Brain of the Sessile-eyed Crustacea; Mem. Nat. Acad. Sci. Washington, 1885, III, pp. 99–110, pl.

Niphargus, a blind genus of the Gammaridae, occurs in the caves of Carinthia, as well as in the underground waters of many springs; and Forel has found it in the depths of the lakes of Geneva and Neuchâtel. Humbert has expressed the opinion that the species living in the Swiss lakes have not been produced by a modification of species possessing sight, such as *Gammarus pulex*, but owe their origin to the immigration of forms inhabiting subterranean water[1].

Numerous other facts having an important bearing on the origin of isolated faunas in lakes might be cited in proof of such a migration of small animals living in subterranean waters; and it is an open question whether the American *Cecidotaea stygia* might not have been an inhabitant of subterranean water before it occupied caves, and even before the formation of the river terraces.

The New Zealand 'frost-fish,' *Lepidotus caudatus*, which has very large eyes, has been described by von Lendenfeld as a deep-sea species. The migration of an inhabitant of the shallower zone into the unillumined depths is a very slow process, requiring for its accomplishment, according to Lendenfeld, many successive generations. If the eye were originally well developed, it might gradually increase in size; but if, on the contrary, weak or unable to adapt itself, owing to over-rapid change of habitat, atrophy and blindness might result[2].

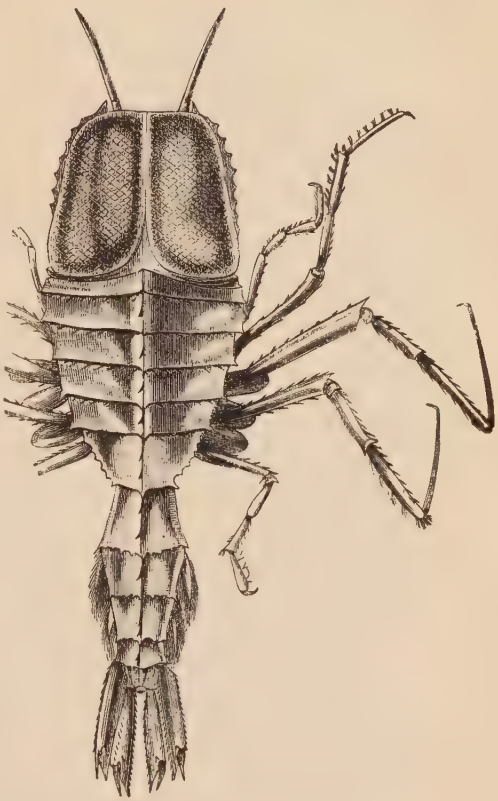


FIG. 18. *Cystisoma Neptunus*, Guér.-Ménev. (after Willemoes-Suhm).
Natural size. Atlantic Ocean off cape St. Vincent, lat. 35° 47′ N., long. 8° 23′ W., in 1,090 fathoms.

We sometimes find, not only towards the upper limit of the abyssal

[1] A. Humbert, Description du *Niphargus puteanus*, var. *Forelli*, Bull. Soc. Vaud. Sci. nat., 1876, XIV, pp. 278–398 and pl.; also Arch. Sci. phys. nat. Genève, 1877, nouv. sér., vol. I, 108, pp. 58–75.

[2] R. von Lendenfeld, Note on the Eyes of Deep-sea Fishes; Proc. Linn. Soc. N.S.W., Sydney, 1885, IX, pp. 699, 700.

region but much below it, even down to great depths, some animals possessing well-developed eyes with others completely blind, and also even, here and there, some which show clearly that the eye has become enlarged. *Cystisoma Neptunus* (Fig. 18), with eyes which meet in the middle line, lives at great depths in the Atlantic, yet has several times been captured at the surface during the night; it appears to belong to that large group of pelagic animals which come to the surface at night and return by day to the depths. The Schizopod *Petalophthalmus armiger*, described by Willemoes-Suhm, is still more characteristic (Fig. 19). Its eye-stalks terminate in vesicular enlargements, which are formed of chitin and show no trace of the structure proper to sight. The eye has been destroyed by its enlargement [1].

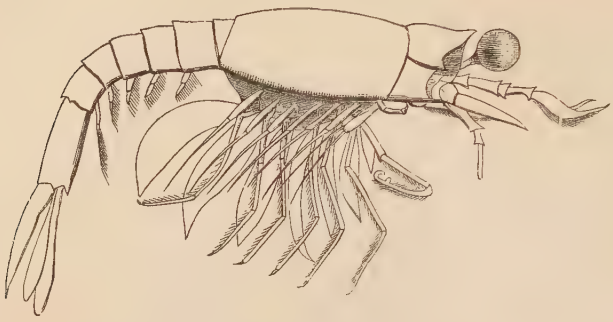


FIG. 19. *Petalophthalmus armiger*, Will. Suhm (after Willemoes-Suhm).
Magnified two diameters; between cape Palmas and Saint-Paul, in 2,500 fathoms; 170 nautical miles east of Saint-Paul in 1,500 fathoms; also in lat. 35° 41′ S. long., 20° 55′ W., about 400 nautical miles west of Tristan d'Acunha group, in 100 fathoms.

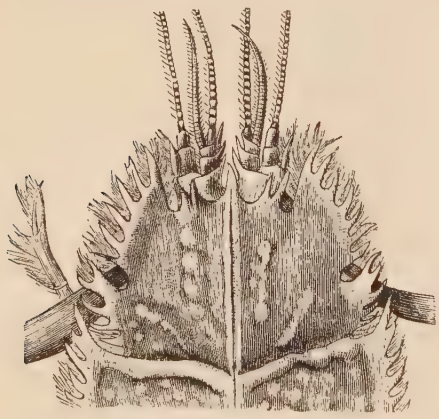


FIG. 20. *Polycheles crucifera*, Will. Suhm (after Willemoes-Suhm).
Magnified four diameters; 450 fathoms; Sombrero, West Indies.

Polycheles and Willemoesia are closely allied to the Jurassic genus, Eryon; the two living forms are inhabitants of the deep sea, and Willemoesia has been found both in the Atlantic and Pacific Oceans at a depth of 1,900 fathoms. The eyes in both these genera are so small and well concealed that for a long time they were overlooked, but Spence Bate affirms that in early stages of development the embryo of Willemoesia possess organs of sight constructed on the usual Crustacean plan [2] (Fig. 20).

We will now turn our attention to the observations on the eyes of

[1] R. von Willemoes-Suhm, On some Atlantic Crustacea from the 'Challenger' Expedition; Trans. Linn. Soc. London, 1875, 2nd ser., I, pp. 23–59; pl.

[2] G. Spence Bate in *Challenger*, Narrative I, 2nd part, p. 524.

Trilobites made by Barrande, long before our present knowledge of the deep-sea fauna had thrown light on their special significance.

In 1872 Barrande summed up all that was then known on the eyes of Trilobites and arrived at the following results [1]:—

Among the Trilobites of Bohemia there are six genera of which all the species are blind, and six which include both blind species and those provided with eyes. The earliest or 'primordial' fauna contains, out of 27 species, seven without eyes; the second fauna, 25 species out of 127; and the third fauna only one species out of 205. The blind species appear in the argillaceous sediments, more particularly in the Cambrian slates, and in the argillaceous deposits d_1, d_3, and d_5, of the lower Silurian *D*, but not in the beds which are predominantly quartzose, and the single blind species of the upper Silurian is found in argillaceous limestone. There are, however, forms with quite abnormally large eyes, such as Aeglina and Remopleurides, and it is just these large-eyed species which are found associated with the completely eyeless ones and once lived along with them [2]. In the case of *Aeglina armata*, as in that of the English species *Aeglina mirabilis*, the enlargement of the eyes is so far advanced that they meet from side to side in the middle, and Barrande calls this the *cyclopean* form (Fig. 22).

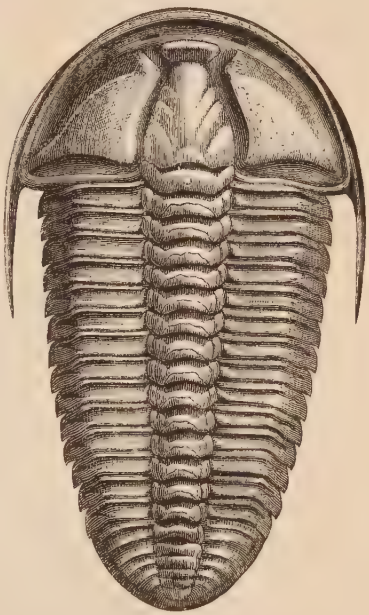


FIG. 21. *Conocephalites Sulzeri*, Schloth. (after Barrande).
Primordial stage; Geinetz, Bohemia; blind.

It is obvious that the eye of Trilobites in the Silurian period was exposed by disuse to an atrophy analogous to that experienced in other classes of animals in later times, and that here too the result was blindness, either by direct atrophy or by enlargement, which is as it were an attempt of the eye to maintain its existence. *Acidaspis mira* (Fig. 23), which occurs in the upper Silurian limestone, shows a stalked eye like that of existing Crustacea, well furnished with organs of sight; the eye of Aeglina (Fig. 22) may be compared with that of *Cystisoma Neptunus* (Fig. 18),

[1] J. Barrande, Système silurien du centre de la Bohême, Supplément au vol. I, 4to, Prague, 1872, pp. 155–164 and 195–197.

[2] 'Pourrait-on penser que les yeux de ces Trilobites étaient destinés à suppléer par leurs dimensions extraordinaires à la faiblesse de la lumière transmise à travers les eaux troubles?' Barrande, tom. cit., p. 162.

which well deserves Barrande's designation 'cyclopean'; it exhibits that process of enlargement which is exemplified by the 'frost-fish' of New Zealand, and with the development of peduncles would lead to the blind goggle eye of *Petalophthalmus armiger*. *Conocephalites Sulzeri*, finally, which is quite blind and occurs in the Cambrian slates of Bohemia associated with *Conocephalites striatus*, a species provided with eyes, corresponds with many examples of complete absence of any external vestige of an eye which are known in the deep sea, in deep inland waters, in subterranean water, and in caves. These species which have become blind lived amidst others which were provided with eyes, as is also the case at present in certain horizons of the deep sea and at the bottom of the lake of Geneva, as has been observed by Forel[1]. Barrande has also found that in the youngest individuals of *Trinucleus Bucklandi*, a blind species of the lower Silurian, there is a little wart in place of the eye in the middle of the cheek, which disappears with age; we are thus reminded of Willemoesia, the Lernaides and other animals which possess in their youth the rudiment of an eye, destined with the advance of age to become partly or entirely lost. In the blind species *Trinucleus ornatus* a young form possessing eyes has not so far been observed (Fig. 24).

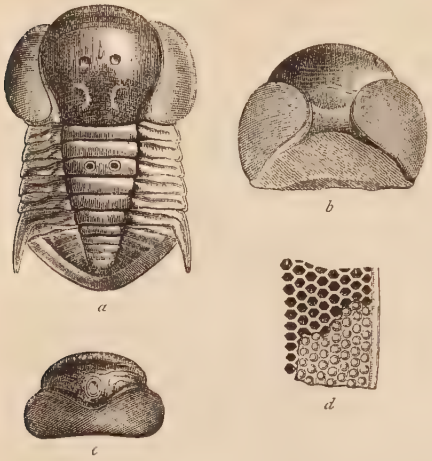


FIG. 22. Cyclopean Eyes (after Barrande).
a. *Aeglina prisca*, Barr., Lower Silurian, d_1, Sancta Benigna, Bohemia; *b*. the same, d_5, Vosek; *c*, *d*. *Aeglina armata*, d_1, near Leiskow.

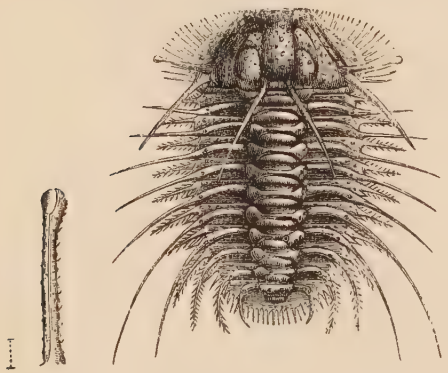


FIG. 23. *Acidaspis mira*, Barr. (after Barrande).
Upper Silurian, *E*, Lodnitz, Bohemia. Stalked eyes.

The numerical statements of Barrande as to the distribution of blind Trilobites in the several stages may possibly be very much modified by later discoveries. Barrande himself observes that the preponderance of blind species in the Cambrian

[1] J. Forel, Faune profonde du lac Léman; Verh. schweiz. nat. Ges. zu Chur, 1873–1874, p. 136.

deposits of Bohemia is to be attributed to Agnostus, an extremely divergent genus. On the other hand, it must not be forgotten that the other Cambrian genera, such as Hydrocephalus, Paradoxides, and in England Anopolenus [1], certainly possess a facial suture and large elongated ocular tubercles, but so far as I know facets have not been observed, except in a very few species, if indeed in any; in the lower Silurian the very large eye, also elongated and actually faceted, of the genus Remopleurides indicates, even by its size, merely an approach to blindness. Indeed so far *Conocephalites striatus* appears to be the only species of the 'primordial' fauna of Bohemia in which it is really possible to observe the facets. Whatever light further investigation may shed on this question, so much is already evident, that even among Silurian animals the twofold process which leads to blindness was already in active operation.

FIG. 24. *Trinucleus ornatus*, Stern (after Barrande).
Lower Silurian d_3, Trubin, Bohemia. Blind.

From this we may conclude that the cause of the blindness was the same as among the existing inhabitants of the deep sea, namely the absence of sunlight; at the same time, however, it appears that the oldest known fauna of the Cambrian system must be regarded as a *transformed* fauna, and thus presupposes the existence of a still older fauna of which we have no knowledge. Just as the ancient salt deposits testify to a correspondence between the past and present, both as to the nature of the substances contained in solution and the order in which they were extricated by crystallization, so the structure of the eyes in the oldest known organisms gives us reason to suppose that the penetration of sunlight into the once-existing seas took place under similar conditions and exercised on the organs of vision the same influence as at the present day.

So far we may pursue the comparison between the past and the present with some degree of certainty; but as soon as we attempt to determine with precision the limits of the abyssal region and to express it by figures, difficulties present themselves. Observations on the depth to which light penetrates, made by sinking a white disc, cannot be accepted as conclusive, since the perceptive faculty of these strangely modified eyes is not known to us, and many of the animals which have become blind, such as *Petalophthalmus armiger* mentioned above, have the habit of coming to the surface of the sea at night. Thus it happens that the expression 'deep sea' is

[1] H. Hicks, Note on the Genus Anopolenus; Quart. Journ. Geol. Soc. 1865, XXI, pp. 477–482, pl. Blind animals which present no exterior trace of an eye, but still possess a concealed rudiment, have been long known as occurring in wells; Bell, Crustacea, 8vo, London, 1853, Introduction, p. xxxi et passim.

understood in most different senses. T. Fuchs, who has given particular attention to this question and who by his exact knowledge of the Tertiary deposits is especially qualified to form an opinion, lays great stress on the influence of light, but places the limit between the littoral zone and the deep sea at a depth of only 40–50 fathoms. Other authorities differ greatly; Günther, for instance, puts the approximate limit of the deep-sea fauna at a depth of 500 to 600 fathoms [1].

For those studies of a general nature in which the expression is employed, it seems to me most convenient to draw the line where the greatest difference of the most general kind makes its appearance, and that is where the diversity of climates ends and the universal fauna begins. This fauna is not subject to those laws of distribution which dominate the shallower zones, and changes in external conditions must affect it in an altogether different manner.

The shallower regions may now be further divided into several zones, and they are distinguished also by the great variety of their sediments. But the undoubted fact must not be overlooked that terrestrial plants and clastic sediments may be carried away into great depths [2]. The presence of beds of little pebbles of variegated quartz in the Cambrian slates of Ginetz, which contain the blind Trilobites mentioned above, is a striking example of this fact. Indeed it must be admitted that in many cases the belt of clastic materials which surrounds many parts of the continents descends into the region of the abyssal fauna, and that it did so even in the ancient seas.

This clastic belt, however, is neither equally broad nor of equal thickness, and where it recedes or thins out the pelagic sediments introduce themselves with continually increasing purity. As a rule they are calcareous, though under certain circumstances limestone may also be deposited at trifling depths or even at the sea-level, for the conditions which govern the formation of marine limestone are very varied. There are massive coral reefs in which living organisms not only secrete the carbonate of lime, but also determine the form of the reef as a whole. These, however, constitute but a small fraction of the calcareous deposits, which for the most part are regularly stratified. Limestone may also be formed by organic débris, i.e. by the breaking up under the action of the waves of the hard calcareous parts of molluscs, corals, and other marine animals; this disintegration may proceed so far that after a storm a broad band of milky water surrounds the limestone reef, as Alexander Agassiz

[1] T. Fuchs in numerous papers; in particular in Verh. k. k. geol. Reichs., 1882, pp. 55–68; Sitz. zool.-bot. Ges. Wien, April 5, 1882; and by the same, Welche Ablagerungen haben wir als Tiefseebildungen zu betrachten? N. Jahrb., 1882, 2. Beilage-Band, pp. 487–584.

[2] Examples in Fuchs, Welche Ablagerungen, &c., p. 498 et seq.

describes in the case of the keys of Florida. Finally limestone may be formed by the showering down on the bottom of the sea of delicate calcareous shells, such as the tests of Globigerina; but at extremely great depths carbonic acid occurs in such quantity that these delicate shells are dissolved and no limestone is formed. There are various signs by which limestone beds reveal the action of the atmosphere and a temporary emergence from the sea. One of these is the interspersion of fragments of light red clay or of argillaceous limestone in the white limestone, such as occurs for instance in the Bermudas. Of a similar nature are the residues of red earth left on the solution of limestone, which are met with on so many coral islands, and in the dolinas of the Karst, where they form the 'terra rossa.' Another indication is the presence under certain circumstances of phosphates, the origin of which may be similar to that of the existing beds of guano. These few examples may suffice to show how various are the phenomena. But they do not exhaust the difficulties, and there is still another question for solution, since some beds of carbonate of lime contain a small, and others a considerable, admixture of carbonate of magnesia, and beds of dolomite may alternate with beds of limestone.

Thus the most careful observation is necessary in the study of stratified limestones.

Many years ago Murchison expressed the opinion that the middle stages of every geological formation consist of limestone, and this idea was worked out in greater detail by Hull in 1862 for several formations, particularly the Carboniferous. The predominance of the terrigenous, that is clastic, elements carried down from the land should, according to Hull, lead us to recognize phases of oscillation of the land, and he thus distinguishes three stages:—

Upper stage . . .	movement . . .	detrital formation.
Middle stage . . .	repose	calcareous „
Lower stage . . .	movement . . .	detrital „

At the same time he concluded from the distribution of the clastic materials in England that we may assume land to have existed to the west and north-west during a series of geological periods[1].

The simpler stratigraphy of the United States has led American geologists to adopt similar views. Newberry, in 1860, starting from the Cretaceous transgression of the west, arrived at the conception of 'cycles of deposition,' i.e. a periodic return of similar conditions of deposition, or in other words an alternation of deposition in shallow water and in the open

[1] E. Hull, On Iso-diametric lines as a means of representing the Distribution of sedimentary Clay and Sandy Strata, as distinguished from Calcareous Strata, &c.; Quart. Journ. Geol. Soc., 1862, XVIII, pp. 127–146, pl.

sea. In 1874 this theory was applied in detail to the Palaeozoic sediments (I, p. 13).

Newberry distinguished the following elements in such a cycle:—(1) coast, (2) region outside the coast, (3) open sea, (4) retreating sea; or sediment 1, mechanically transported; 2, mixed; 3, organic; 4, mixed. Within a larger cycle smaller cycles owing to oscillation would arise, as is supposed to have happened in the Carboniferous, and strictly speaking only three elements can be distinguished in a cycle, namely, two deposits in shallow water separated by deposits in the open sea. The Palaeozoic aera would include four great cycles [1].

Other investigators in America have followed in the same direction, most prominently Dawson in 1868 [2].

A study of the Tertiary series of Belgium had led André Dumont to recognize that the intercalation of thick beds of coarse pebbles indicates some particular change in physical conditions; he therefore attempted to determine the limits of the Tertiary stages by means of these pebble beds.

Rutot and van den Broeck have renewed this attempt. They endeavoured to show that in secular, continental subsidence (positive movement), the margin of the sea as it advances towards the interior covers the land with a layer of coarse beach pebbles (*gravier d'immersion*); and on this, as the movement continues, finer sand, and finally the clay of the deeper marine zones, is laid down; if the oscillation then passes into its opposite phase, i.e. if negative movement succeeds, the clay will again be followed by sand, and this by an upper layer of rolled pebbles (*gravier d'émersion*), which it is true is often not fully developed or is destroyed by erosion. This series—pebbles of submergence, sand, clay, sand, and pebbles of emergence—is called a complete 'cycle sédimentaire' and regarded as equivalent to a complete secular oscillation. The clay thus takes the form of a lens thinning out towards the land. In this particular case no calcareous formation of any importance results; only clastic materials are deposited. The cycles may be incomplete or the corresponding deposits removed in part by erosion. The author has cited as an example the lower Tongrian marine stage, consisting of *Tg* 1*a* (pebbles), *Tg* 1*b* (sand), *Tg* 1*c* (clay), *Tg* 1*d* (sand), which all belong to the zone of *Ostrea ventilabrum*; then comes *Tg* 2*a* (sand with *Cytherea semistriata*), *Tg* 2*b* (clay with *Cytherea incrassata*), *Tg* 2*c* (sand with *Cerithium plicatum*) [3].

[1] J. S. Newberry, Circles of Deposition in American Sedimentary Rocks; Proc. Amer. Assoc. Adv. Sci. Portland, Maine, 1873, 8vo, Salem, 1874, pp. 185–196.

[2] J. W. Dawson, Acadian Geology, 2nd ed., 1868, pp. 135–138.

[3] A. Rutot, Les phénomènes de la sédimentation marine étudiés dans leurs rapports avec la stratigraphie régionale, Bull. Mus. R. Hist. nat. Bruxelles, 1883, II, pp. 41–83; E. van den Broeck, Note sur un nouvel mode de classification et de notation graphique des dépôts géologiques basé sur l'étude des phénomènes de la sédimentation marine, tom. cit., pp. 341–369.

Considerations of this kind lead to the supposition of very frequent and very regular alterations of the coast-line which are difficult to reconcile with the principles of the elevation theory, and Newberry chooses expressions such as: advance of the sea and retreat of the sea, or the same words as were employed by Brogniart, Omalius d'Halloy, and others before the prevalence of the elevation theory (II, p. 13).

According to these views the limits of a system, sometimes even of its subordinate stages, might be regarded as an expression of the negative phase, while the positive phase would correspond approximately to the middle of the formation. But it is a fact that the nomenclature created in Europe, and with it the principal limits of the stratigraphical systems, have been found applicable in all geographical latitudes and in the most distant regions of the globe. It is impossible, however, that a cycle of this kind can affect in the same sense the whole surface of our planet. We must suppose that positive areas in one part are opposed by negative areas in another. The theory of elevation, in particular, is inconsistent with the conception of a positive or negative movement extending simultaneously over the whole earth, or even over a very large part of it; diversity of the movement is characteristic of this theory.

The thickness of the sediments themselves, however, sometimes amounts to thousands of feet. In every individual case, these sediments, as they increased in thickness at any given place where a section has been studied, must necessarily have produced a constant diminution in the depth of the sea.

If the level of the coast-line remain wholly unchanged they must finally reach the surface of the sea, and affording the observer evidence of shallow water and life under littoral conditions, may lead him to the mistaken inference of a negative movement. Every negative movement is strengthened in its effects by the progress of sedimentation, and every positive movement increases the depth of the sea only by so much as it exceeds the thickness of sediment forming at the same time and place. The same considerations apply to an oscillatory movement. It may then happen that the thickness of the sediment, limestone for example, may equal the positive excess, or Sed. = Pos. — Neg. The upper surface of the sediment will then correspond to the highest level of the positive phase, that is to the sign *e* or *m* in the table on p. 25; and it is in no small degree probable that this surface will lie above the sea-level and lead us to infer an elevation of the land. We shall meet with this case in recent limestone formations and coral islands.

The process may be represented somewhat more exactly. The thickness is often so great, that by increase of the local attraction it raises the sea-level a perceptible amount, *a*. At the same time over the whole earth sediment is being continually carried down into the sea; thus the sea is

gradually forced to overflow its shores, and for any given interval of time by a quantity σ. The formula which represents the increase in the depth of the sea is therefore

$$(\text{Pos.} + \alpha + \sigma) > (\text{Neg.} + \text{Sed.})$$

and for a diminution in the depth of the sea:

$$(\text{Pos.} + \alpha + \sigma) < (\text{Neg.} + \text{Sed.}).$$

In this connexion I cannot repress a doubt that in some of the most frequently repeated statements as to the measured thickness of clastic deposits, particularly of the Carboniferous system, some exaggeration in the figures is to be feared. It is not always permissible in fact to take the sum of the several thicknesses, as for instance in limestone formations, for this method assumes that the sediments in question were deposited vertically, one above the other, while some at least were really formed on talus slopes advancing towards the sea, and thus, to a certain extent, beside each other or resting against one another. In this way we might obtain figures for the thicknesses of clastic sediments which would far exceed the truth; still in any case these thicknesses, even if strictly estimated, would certainly amount to many thousands of feet.

1. *The North Atlantic continent.* A belt of clastic sediments affords a basis of hypothesis as to the position of the continent from which it has been derived. In North America we meet with the greatest thicknesses of Cambrian and Silurian shale and sandstone in the vicinity of the Atlantic coast, namely in the east and south-east of Canada, in the adjacent north-eastern part of the United States, and in the Appalachians. Thence the thickness diminishes towards the Mississippi; shale and sandstone diminish in importance, while limestone increasingly predominates.

We see something similar, although not with equal distinctness, in the north of Europe. In the British Isles great thicknesses of sandstone and shale are present, and the same is the case in the mountains of Norway; in Sweden and the Baltic provinces the thickness rapidly diminishes, and in the Silurian the limestone predominates more and more.

This fact has led American geologists to conjecture that the continent which furnished these sediments occupied the site of the existing North Atlantic Ocean. In the same way in England, Godwin-Austen, and after him Geikie, regarded the crystalline rocks of Scandinavia, with their continuation into the Hebrides, as the remains of the Silurian continent, and Hull has defended with great zeal the theory of a vanished Palaeozoic Atlantis [1]. From the following, however, it will appear that this continent persisted as such up to a very recent epoch in the history of the earth.

[1] E. Hull, On the Geological Age of the North Atlantic Ocean; Trans. R. Dublin Soc. 1885, new ser., III, pp. 305–320.

When we attempt to study in greater detail the manifold subdivisions of the marine beds as they succeed each other in the east and west of this primaeval continent, we are at once struck by the far more fortunate position of the observer in America as compared with his colleague in Europe. In the west, during the accumulation of these deposits, orogenetic movements took place only in the Green mountains, and flat-bedded Palaeozoic sediments still extend over vast areas far away up to Kansas and Nebraska. Even where folding followed later, as in the east of Canada and the Alleghanies, we have as a rule no difficulty in correlating the stratified succession with that of the more distant parts of North America. In Europe, on the other hand, as soon as we have crossed the narrow zone of the Hebrides we encounter the Caledonian folds with their great overthrusts, and upon the ruins of these worn-down Silurian mountains the Old Red sandstone lies horizontally. If we proceed further into the interior of this continent we again find the ancient marine deposits still for the most part folded and fractured; it requires, therefore, a combination of perseverance, exactitude and sagacity, and these in no small degree, to establish a correspondence between the members of the stratified series in regions at all remote from one another. It is not till we reach Sweden and the Russian plain that we meet with stratigraphical relations as favourable to study as in the United States.

Let us again turn our attention to that region.

The thickness of the Palaeozoic sediments decreases as we proceed from the Atlantic Ocean towards the Mississippi. In the Rocky mountains also it is trifling, but beyond them, towards the Wahsatch and Uinta, the sediments thicken out again very rapidly, as they also do in the eastern part of the Basin ranges, according to Clarence King up to about long. 117° 15′ W., and then they disappear. In California only the Carboniferous limestone is known. Beyond long. 117° 15′ W. there thus lay in all probability a second continent, which bounded the Ocean on the west [1].

As early as 1859, James Hall had described in a masterly survey the classification and distribution of the Palaeozoic beds in the east and centre of the United States. The years which have since elapsed have confirmed his results in all essential points, and they form the basis of the comparisons which follow here [2]. The investigations of Canadian geologists and those carried out in the great ranges of the west complete the picture.

In Newfoundland, New Brunswick, and at Braintree, Massachusetts, there are beds, chiefly shales, in which are found species of the genus Conocephalites, both blind and provided with eyes, as well as a number of other Trilobites, which closely agree in general character with the

[1] C. King, U. S. Geol. Expl. 40th Par., I, pp. 127–248, map.

[2] J. Hall, Geological Survey of New York; Palaeontology, III, 4to, Albany, 1859, pp. 1–96.

'primordial' fauna of Ginetz and Skrey in Bohemia[1]. In America also they represent the oldest animals so far known. This group of strata is called the St. John's group. In the whole central part of the United States they appear to be absent, and it is only when we reach the Wahsatch and Eureka, in Nevada, that we again encounter them[2].

In the east, from Labrador and Newfoundland as far as New York and Vermont, and again in the west, in Utah and Nevada and in British Columbia on the east border of the Rocky mountains, this group is followed, according to Walcott, by a middle member of the primordial or Cambrian series, the *Georgia group*, with an independent fauna. Limestone plays a leading part in its composition; this group again is not yet known in the central part of the United States[3].

The distribution of the last member, the *Potsdam sandstone*, is much more extensive, and may be traced from Belle Isle through Canada down into the north-east of the United States, through Pennsylvania and Virginia and further to the south-west into Tennessee, where it becomes thicker and alternates with dolomitic limestone; then in flat-lying beds still further into Texas, and again to the north in an elongated zone which lies horizontally on the south border of the Canadian shield from lake Huron through Wisconsin and Iowa[4]. From Iowa, where, according to D. D. Owen, several subdivisions may be distinguished, the zone of sandstone continues to the west. It crops out in the Black hills from the plain of Dakota, and then as an almost continuous border, sometimes gently inclined, sometimes steeply upturned or even inverted, surrounds the Archaean ridges of the Rocky mountains. Further west in Nevada the fossils of the Potsdam group lie high above those of the earlier stages.

The stratified series of Eureka begins according to Hague and Walcott with about 1,500 feet of brownish-white quartzite, the upper part of which becomes shaly and calcareous; the first traces of the middle Cambrian or Georgian fauna appear here. There then follows about 3,000 feet of grey limestone, containing the same fauna, to which, at the summit, species of the upper Cambrian or Potsdam fauna are added. The

[1] G. F. Mathew, Illustrations of the Fauna of the St. John's Group, Trans. R. Soc. Canada, Montreal (in vols. I, II, and III, 1884–1886); C. D. Walcott, On the Cambrian Faunas of North America, Bull. U. S. Geol. Surv. Territories, 1884, No. 10, p. 49, pl.

[2] A. Hague, Abstract of Report on the Geology of the Eureka District, Ann. Rep. U. S. Geol. Surv. III, 1881–1882, by Powell, Dir., 8vo, Washington, 1883, p. 248 et seq. C. D. Walcott (Palaeontology of the Eureka District; U. S. Geol. Surv. Monograph VIII, 1884) has described this fauna and in particular the abnormal development of *Olenellus Howelli*.

[3] Walcott, Second Contribution to the Studies on the Cambrian Faunas of N. America; Bull. U. S. Geol. Surv. Territories, 1886, No. 30, pp. 729–952.

[4] J. Hall, Note in Proc. Amer. Assoc. Adv. Sci., XXXI Meeting, held at Montreal, 8vo, Salem, 1883, pp. 63–65.

limestone is followed by 1,600 feet of shale, 1,200 feet of limestone, and 300 feet of shale. All these belong to the Potsdam stage.

A very singular picture is presented to us by this ancient Ocean. Shore deposits, with cracks produced by the drying action of the sun and filled with millions of valves of Lingula, form the series known as the Potsdam sandstone, which still lies flat on the south border of the Archaean shield of Canada; in Nevada, far to the west, these deposits swell out to a great thickness, while limestone and shale take the place of sandstone.

Let us now turn to the Black mountains as described by Newton and Jenney. The Potsdam sandstone, 200 to 300 feet thick, presenting at its base a coarse bed of beach pebbles with auriferous sand, includes some glauconite beds and a little limestone; it rests in discordance on the upturned edges of the Archaean schist. Here we have before us an Archaean reef of the Cambrian sea, which in the last stages of its existence was completely covered with sand. Over the Potsdam sandstone, however, follows—not the succeeding systems of the lower Silurian, upper Silurian, and Devonian, but the marine deposits of the Carboniferous which lie immediately on the sandstone and apparently in complete conformity with it [1].

In the Rocky mountains the Potsdam sandstone is similarly overlain by these same deposits of the Carboniferous system.

Eight degrees of latitude further south and also further to the west is the Grand cañon of Colorado, excavated in horizontal beds of Carboniferous limestone. Powell and Dutton, however, state that the Carboniferous series, 4,000 to 4,500 feet thick, rests on the edges of inclined beds, probably Cambrian, which are cut off by the plane of transgression. This is an example, exposed for miles along the cañon, of a plain of erosion produced by the advance of the coast-line [2].

Throughout the whole of Arizona also, the Carboniferous rests directly on Archaean or possibly Cambrian rocks, and up to the present it is only in Nevada that the western development as represented by the lower Silurian has been recognized.

Thus the Carboniferous transgression circumscribes the region in which it is possible to study the post-Cambrian deposits.

The oldest fossiliferous sediments of North America enable us therefore to recognize the following:—

The St. John's group and the Georgia group, the two lower members, are only known in the east and in the west. A wide interval separates these two provinces. The third member, the Potsdam group, covers them

[1] H. Newton and W. P. Jenney, Report on the Geology and Resources of the Black Hills of Dakota; U. S. Geogr. and Geol. Surv. of the Rocky Mountain Region, 4to, Washington, 1880, pp. 80–106 and 109.

[2] C. E. Dutton, Tertiary History of the Grand Cañon District, p. 178 et seq.

both and extends over the whole region. In Nevada it increases in thickness and limestone makes its appearance, but in Dakota and over the whole of the north border, where it lies on the Archaean rocks of Canada, it is without doubt a coast formation deposited in transgression. This example shows that a strictly littoral formation, deposited in transgression, must be regarded not as the sign of a negative phase, but, on the contrary, as a proof of the advance of the sea on the land.

Notwithstanding the close attention which has been given to the classification of the Cambrian beds in England, and the extreme precision with which Linnarsson and Brögger have distinguished the several members of this system in Scandinavia where they are less thick, yet I dare not venture to make any parallel with the American beds beyond the correlation of the St. John's group with the deposits of Ginetz in Bohemia. A transgressive littoral group, which might be compared with the Potsdam sandstone, has not been observed in Europe. Its upper limit, or the base of the lower Silurian, is however expressed with equal clearness on both sides of the Ocean by the change of fauna.

2. *The upper limit of the Silurian formation.* In the east of North America the upper Silurian series begins with the Clinton group or the Medina sandstone; both show distinct signs of variable conditions and somewhat shallow water. Over these beds lies the Niagara limestone, very widely distributed and containing a rich marine fauna; it is generally regarded as the equivalent of the Wenlock and Ludlow beds in England and of the upper Silurian limestone *E* of Bohemia. This would represent the middle phase of the Silurian cycle. Then follow beds deposited in shallow water, so shallow indeed that layers of gypsum and rock-salt were formed over wide areas. These form the Onondaga saliferous group, a sandy formation bearing the marks which attend the concentration of sea-water, yet attaining a thickness of 1,000 feet. It presents itself with these characters in New York State, particularly in the western part, and proceeds with diminished thickness, on the one hand into the south-west of Virginia, and on the other to Wisconsin, often broken up into patches by erosion. In the interior of the continent, towards the Mississippi, this member is characteristically absent, and the upper Silurian Niagara limestone is directly succeeded by the Devonian limestone.

Here then we enter the open sea; but nearer to the ancient coast we find the saliferous group passing upwards through many alternations of sediment into a brownish-yellow dolomitic limestone known as the 'Waterlime.' This extends beyond the saliferous group into Illinois and Iowa, and contains in some places the remains of the great Crustacea belonging to the genera Eurypterus and Pterygotus. This beyond all doubt is also a shallow water formation.

Let us now investigate the upper limit of the Silurian in the north of

Europe. In the highest parts of the Ludlow series we meet here and there with a 'bone-bed' containing numerous remains of fishes drifted together; then follow beds of variable character, but always littoral, which Murchison describes as 'Passage beds'; these are sandstones with Lingula, or marly shales with fish remains and great Crustacea, notably the gigantic *Pterygotus anglicus*; between these again are shales with Lingula and thin layers of sandstone. Where the earliest sediments of the Old Red sandstone are to be seen superposed on the Passage beds, we observe that remains of the same fishes and Crustacea are continued up into them, and thus the lower part of the sandstone is often assigned to the Silurian [1].

The Silurian concludes in England as in North America with an unmistakable and considerable diminution in the depth of the sea.

In the Baltic region as on the island of Oesel we find a similar condition of things. According to F. Schmidt, in the uppermost beds of the Silurian, a yellow platy dolomite, poor in fossils, makes its appearance, or a grey sandstone containing many upper Silurian corals and other fossils. In the platy dolomite Eurypterus again occurs in abundance, accompanied by Pterygotus, but here, as in Gothland, the beds with Eurypterus are succeeded by others still containing upper Silurian fossils [2].

Finally, the same succession is repeated in the river valleys of eastern Galicia and in the adjacent parts of Russia. F. Schmidt, who is so thoroughly acquainted with the Silurian deposits of the Baltic, has himself visited these regions and recognized the correspondence. The upper

[1] R. J. Murchison, Siluria, 4th ed., 1867, p. 136; by the same, On the discovery by Mr. R. Slimon of Fossils in the Uppermost Silurian Rocks near Lesmahago in Scotland, Quart. Journ. Geol. Soc. 1856, XII, pp. 15–25. For the ascent of the fossils into the Old Red sandstone see R. Etheridge, Anniversary Address of the President; Quart. Journ. Geol. Soc., 1881, XXXVII, p. 178. A visit to the habitat of horny-shelled brachiopods led me some years ago to examine a great number of the facts quoted here. Horny-shelled brachiopods have subsequently been found in deep water also. The fauna of the deep sea has become known, and with this knowledge a complete alteration in the previously accepted views of the Cambrian fauna of Bohemia. At that time elevation and depression of the land was the accepted theory, but it was the progress of these particular studies which led me first to doubt the correctness of the prevailing opinion, next to recognize the extent of the Cenomanian transgression, and finally to results which were no longer in accord with the traditional method of explanation. Ueber die Wohnsitze der Brachiopoden; Sitz. k. Akad. Wissensch. Wien, 1859, XXXVII, pp. 185–248, and 1860, XXXVIII, pp. 151–206. An account of the Passage Beds and their littoral characters occurs in the second part, pp. 189–191. In this memoir the recurrences of the lower Silurian in the United States (p. 182 et seq.), which are not described in detail here, are also discussed; the comparisons made there for the Utica shales are completely in accordance with the results of the admirable work of C. D. Walcott, The Utica Slates and related Formations, Trans. Albany Inst., 1879, X.

[2] F. Schmidt, Revision der ostbaltischen silurischen Trilobiten nebst geognostischer Uebersicht des ostbaltischen Silurgebietes; Mém. Acad. Imp. Sci. Saint-Pétersb., 1881, XXX, No. 1, p. 49 et seq.

Silurian is again represented in the same manner as in England and the Baltic provinces. Here also Eurypterus occurs in the equivalents to the Ludlow beds, and Silurian fossils appear to be present above the beds with Eurypterus [1].

We are thus in a position to follow the beds with Eurypterus from the centre of the United States as far as the Dniestr. In New York State the saliferous group underlies the platy dolomite with Eurypterus, as though the latter no longer corresponded with the phase of maximum depression of the coast-line.

In England the Eurypterus beds pass upwards into the lowest beds of the Old Red sandstone. In Gothland, Oesel, and on the Dniestr, they are again succeeded by a few beds with marine Silurian fossils. But everywhere, from Iowa to Podolia, a zone of shallow-water deposits distinguished by strange gigantic Crustacea makes its appearance towards the upper limit of the Silurian.

In America this shallow-water zone thins out to the south-west, and the marine upper Silurian limestone is directly succeeded by Devonian limestone; in Europe it is the same, but the thinning out occurs at a greater distance from the original coast-line. In the best-known regions of the interior, that is Bohemia, the upper Silurian limestone is also succeeded by another limestone, which, according to recent investigations, we may refer to the lower Devonian.

3. *The Devonian System.* In the British isles and in the Baltic provinces the greater part of the Devonian system is represented by the Old Red sandstone, which contains fishes (among them curious, heavily armoured ganoids), and here and there terrestrial plants, but no corals nor marine shells. This red sandstone comprises divers subdivisions of the Devonian; and in England, as we have seen above, its lowest beds may be assigned to the Silurian.

In central Europe the case is different; the red sandstone is absent, and its place is taken by slates and quartzite, also even by limestone, with a rich marine fauna. Our knowledge of this part of the stratified series has been greatly enlarged by Beyrich and Kayser's researches in the Harz. Kayser has shown that the fauna of the limestones which are intercalated with the lower Devonian 'Wieder Schiefer' of the Harz corresponds to the upper divisions of the Bohemian series, hitherto assigned to the Silurian. It is on these fossiliferous localities of the Harz and Bohemia that Kayser has based his Hercynian stage [2].

[1] F. Schmidt, Einige Bemerkungen über die podolisch-galizische Silurformation und deren Petrefakten; Verh. k. russ. min. Ges. St. Petersb., 1876, 2. Ser., X, pp. 1–21, map.

[2] E. Kayser, Die Fauna der ältesten Devonablagerungen des Harzes, Abh. z. geol. Specialkarte v. Preussen, 1878, II, Heft 4, pp. 1–293, pl.; and by the same, Ueber die Grenze zwischen Silur und Devon (Hercyn) in Böhmen, Thüringen und einigen anderen

Kayser justly compares the appearance of this new marine stage with that of the different marine faunas, which, like the fauna of the Alpine Trias, the Rhaetic, and the Tithonian, are unknown in northern Europe. They are the oceanic representatives of those periods, and their equivalents in the north are either sublittoral sediments or non-existent. We may trace the Hercynian stage, i.e. the formations of the open sea during the lower Devonian period, from the Pyrenees, where it is represented by argillaceous beds [1], to the Harz, where it occurs as limestone included in slates, and to Bohemia and the eastern Alps, where it is pure limestone. In northern Europe it is not to be found.

Having made these general observations, let us return to the Eurypterus beds of northern Europe.

It is certain that in England Eurypterus ascends into the lower beds of the Old Red sandstone, and that in general the relations of these lower beds with the Silurian are so intimate that we must include them in that system. The upper part of the sandstone has been subdivided, on stratigraphical and faunistic evidence, in very various ways; but all lead to the conclusion that it represents a very large part of the Devonian, although further to the south, in Devonshire, the Devonian already presents itself as a marly and in part also calcareous series, with a fairly rich marine fauna [2].

The red sandstone extends in many patches of flat-lying beds over the folded Silurian strata of the Caledonian chain into the extreme north of Scotland; it forms the Orkney and Shetland islands (Fig. 10, II, p. 78).

In the Baltic provinces the red sandstone is likewise superposed on the uppermost Silurian strata; but, according to the unanimous opinion of English and Russian geologists, the fish remains of the Baltic sandstone do not represent the lower, but the middle and upper beds of the British sandstone, particularly as developed in Scotland [3]. Between the highest Silurian with Eurypterus of Oesel and the red sandstone immediately above it there is a gap, and the lower Devonian is not represented.

We have seen previously that towards the north this red sandstone overlaps the several stages of the Silurian, so that between St. Petersburg

Gegenden, N. Jahrb. Min., 1884, II, pp. 81–86. I here restrict the Hercynian to the stage *F*, following O. Novák, Zur Kenntniss der Fauna der Etage Ff_1, Sitz. k. böhm. Ges. Wiss., 1886, and Frech, Zeitschr. deutsch. geol. Ges., 1886, XXXVIII, p. 917. The position of g_1 remains for the present doubtful.

[1] C. Barrois, Sur la faune de Hont-de-Ver (Haute-Garonne); Ann. Soc. Géol. du Nord, 1886, XII, pp. 124–144, pl.

[2] Geikie, On the Old Red Sandstone of Western Europe, Trans. R. Soc. Edinb., 1878, XVIII, pp. 345–452; E. Hull, On a proposed Devono-Silurian Formation, Quart. Journ. Geol. Soc. 1882, XXXVIII, pp. 200–209, etc.

[3] Geikie, tom. cit., p. 362; Lahusen in Schmidt, Revision, p. 80, &c.

and Gatschina the upper Silurian is already entirely concealed, and only a narrow band of lower Silurian remains visible; at the point where the Sjas enters lake Ladoga the Cambrian is alone to be seen; further to the north, as far as the White sea, the sandstone rests directly on the Archaean (II, p. 45). In an instructive series of charts representing the transgressions to which Russia in Europe has been subjected, Karpinsky has assumed that the patches of quartzite which occur at Onetz and at Powjenez, north of lake Onega, as well as the unfossiliferous sandstone of the island of Kildin, near the Murman coast, and of the peninsula of Rubatsch, may also be assigned with considerable probability to the Old Red sandstone [1]. Of more doubtful age are the isolated patches of sandstone in the northernmost parts of Norway; in Spitzbergen, however, we again meet with the fish remains characteristic of the Old Red sandstone in the Liefde bay beds, but no marine Silurian is yet known to underlie it (II, p. 69). In Greenland also we have noticed patches of red sandstone, unfossiliferous it is true, resting on the Archaean in the peninsula separating the fjords of Sermilik, Yunugdliarfiak, and Igalliko (II, p. 73).

In the peninsula of Gaspé, however, and in New Brunswick, the Devonian fishes of the red sandstone have already been found; here also they are associated with terrestrial plants, and the correspondence of both plants and fishes with those of Europe is, according to Dawson, beyond doubt [2].

It cannot be denied that in this northern region a certain resemblance with the Indian Ocean exists, the red sandstone playing here the same part as the Gondwána beds do there.

The open sea of the Devonian period did not extend over Spitzbergen, nor over Gaspé, and it was probably excluded over the whole distance from Gaspé to Greenland. The transgression of the middle Devonian sandstone over the several stages of the Silurian in northern Russia shows, on the other hand, that previous to the transgression some parts of the Silurian had already been worn away by denudation, as had also the Caledonian folds.

Let us now pass to a somewhat closer consideration of the Russian transgression.

In Livonia and Courland a broad zone of red sandstone with fish remains occurs, which, according to Grewingk, is about 100 meters thick;

[1] A. Karpinsky, Skizze der physiko-geographischen Verhältnisse des europäischen Russland in den vergangenen geologischen Perioden; vorgetragen in der öffentlichen Sitzung der Akademie am 29. Dec., 1886; Beitr. z. Kenntn. des Russischen Reiches, III. Folge, St. Petersburg, 1887, p. 14, note.

[1] W. Dawson, Canadian and Scottish Geology; Trans. Edinb. Geol. Soc., 1885, V, pp. 112–122 et passim.

above it on the south follows a series of dolomite and limestone with marine fossils, gypsum, and beds of marl containing pseudomorphs of rock-salt. The thickness of this middle group is estimated by Grewingk at 70 meters. Upon it, forming a narrow zone, about 20 meters thick, lies an upper bed of red sandstone[1].

Near Kholm, on the Lovat, in the government of Pskov, 300 kilometers from the southern boundary of the Silurian zone, Karpinsky found the Silurian once more cropping out from beneath this series of transgressive beds, and it appears that here also there is the clearest evidence of a partial denudation of the Silurian anterior to the transgression, and consequently during the lower Devonian period[2].

Tschernyschew and Wenjukow have studied the fossils of the limestone and dolomite beds. They belong to the middle Devonian, and show that after the deposition of the lower sandstones, which are also assigned to the middle Devonian, a period occurred during which gypsum and a small quantity of rock-salt crystallized out in lagoons, but in some localities there was deeper water inhabited by a genuine marine fauna. Then followed once more a deposition of sandstone[3].

To the east and south-east the sandstone gradually disappears; its last known traces are seen in Orel beneath the middle Devonian limestone.

The brief account by Tschernyschew shows this very clearly. The upper and middle Devonian with a rich marine fauna occur in the governments of Orel and Voronezh; far to the north their presence beneath the plain has been ascertained by borings. These facts have been represented by Karpinsky in a diagram which shows wedge-shaped beds of limestone thinning out into the sandstone towards the north. The thinning out of the limestone may be plainly seen on the Volkhov[4].

To the north-east on the Uchta, which flows into the upper Petchora, we again encounter the middle Devonian, and above it the *Domanik shales.*

These have been described by Keyserling; the name is said to be derived from the Russian word 'dym' (smoke), for the quantity of bituminous matter contained in the shale is so great that it burns readily with a smoky flame. Petroleum exudes from the ground. Cake-shaped nodules

[1] C. Grewingk, Geologie von Liv- und Kurland, 8vo, Dorpat, 1861, pp. 9-61; by the same, Erläuterung zur zweiten Ausgabe der geognostischen Karte Liv-, Est- und Kurlands, Arch. Nat. Liv.-Esth-Kurlands, Dorpat, 1879, ser. 1, VIII, pp. 15 et seq.

[2] A. Karpinsky, Zur Geologie des Gouvernements Pskow; Mél. phys. chim., 1886, XII, p. 622.

[3] T. Tschernyschew, Materialien zur Kenntniss der devonischen Ablagerungen in Russland, Mém. Com. Géol. Russie, 1884, I, no 3, pp. 77-81; P. N. Wenjukow, The Fauna of the Devonian System of North-west and Central Russia (in Russian), 8vo, St. Petersburg, 1886.

[4] Karpinsky, Skizze, pp. 17-18, note 1.

of limestone occur in an intercalated bed of green marly clay; they correspond with the upper Devonian Goniatite beds of the Rhine district[1].

It is not until we reach the Ural that the lower Devonian appears, and the Hercynian limestone; this corresponds to the gap beneath the Baltic transgression.

In the same way we see in England and Scotland various regions of the Old Red sandstone; then more to the south, in the fragments of the folded Armorican and Variscan ranges, the Devonian system, of great thickness and very diverse character; consisting in Devonshire, the Ardennes, on the Rhine and in the Harz, the Thüringerwald, and the Sudetes, of quartzite, slates, and limestone in various alternations, it reappears, with many similar characters, near Graz on the border of the eastern Alps. In Bohemia the quartzites are absent and the thickness much diminished; the Hercynian limestone rests on the Silurian limestone. Within the eastern Alps also, in Styria, Carinthia, and Carniola, the only representative of the Devonian system so far recognized is the Hercynian limestone[2].

In these regions, therefore, the Hercynian transgression does not, as in Russia, afford definite proof of its existence; still, here also, in spite of all subsequent disturbances, we plainly perceive from the distribution of the sediments that the littoral formations predominate in the north, and the pelagic in the south[3].

We may now emphasize the fact that, according to the marine remains which have been found in the dolomite and limestone beds of Livonia and

[1] A. Graf Keyserling und P. v. Krusenstern, Wissenschaftliche Beobachtungen auf einer Reise in das Petschora-Land, 4to, St. Petersburg, 1846, pp. 396 et seq.

[2] G. Stache, Ueber die Silurbildungen der Ostalpen, mit Bemerkungen über die Devon-, Carbon- und Perm-Schichten dieses Gebietes; Zeitschr. deutsch. geol. Ges., 1884, XXXVI, pp. 277–378.

[3] 'The thick lower Devonian slates and grauwacke deposits of the Rhine, France, and Spain, in spite of their imposing development, represent only a local formation in western Europe, like the Trias formation of Germany, and indeed their petrographical characters as well as their poverty-stricken uniform fauna, in which Cephalopods are almost completely absent, show that they must be regarded as *shallow-sea* deposits. It was always to be expected that it would be possible in time to point *to the deep-sea equivalents of these shallow-water deposits*; as such the Hercynian series of the Harz and of Bohemia must be regarded.' A. Kayser, Die Fauna der ältesten Devonablagerungen des Harzes, p. 288. For the sake of completeness it may be observed that, in the Alburs, Tietze met with the red sandstone beneath marine Devonian deposits; no organic remains were found; Jahrb. geol. Reichs., 1877, XXVII, p. 389. Opinions as to the littoral or lacustrine formation of the red sandstone have been discussed by Godwin-Austen, Rep. Brit. Assoc. Adv. Sci., 1869, p. 88 et seq.; Ramsay, Quart. Journ. Geol. Soc., XII, p. 38, and XXVII, p. 241; Rupert Jones, A Monograph of the Fossil Estheriae, Palaeogr. Soc.; Hull, Quart. Journ. Geol. Soc., XXXVI, pp. 252–274; Gosselet, Bull. Soc. géol. de Fr., 3e sér., I, pp. 409–417.

Courland, the maximum of transgression in these countries must be placed in the middle Devonian (Stringocephalus horizon). At this period the Devonian sea attained its greatest extension in Russia. Immediately after, both in respect of age and distribution, follow the upper Devonian Domanik shales of the Petchora region (Goniatite shales); then marine formations are seen no more until the beginning of the Carboniferous period.

Bearing this result in mind let us turn our attention to North America. Kayser has shown that the 'lower Helderberg group' of New York is the equivalent of the Hercynian stage. We need not stay to dwell on its limited distribution, the detailed classification of the succeeding series, or the complicated relations which arise in New York State from local unconformities [1]. We will confine our attention to one particular group of the Devonian beds of North America.

The middle Devonian is represented in New York State by the Marcellus shale, the Hamilton group, and the Genessee shale. The Marcellus shale below and the Genessee shale above present so many points of resemblance as regards their fossils that Williams regards the Genessee fauna as a recurrence of that of the Marcellus shale. The intervening Hamilton group includes beds of limestone with numerous marine fossils, and one in particular, the Tully limestone, irregularly distributed towards the summit, contains *Rhynconella cuboides*, a well-known middle Devonian species found in England, Russia, and on the Rhine [2].

In the Genessee shales of New York State, close to lake Ontario, considerable quantities of bituminous matter occur, and Clarke has described a particular bed, formed of millions of shells of *Styliola fissurella*, a little Pteropod, scarcely 1½ to 2 millimeters long, which were washed up on the coast by the waves of the Devonian sea; among them lie trunks of Lepidodendron, Dadoxylon, and other trees which were stranded at the same time. Similar beds of Styliola also occur in the Marcellus shales [3].

These three members of the American series are universally recognized as forming the middle Devonian of North America; they are the equivalents of the dolomite and limestone beds of Livonia and Courland. Above them lies the Naples shale, also containing bituminous beds in places, with

[1] For these complicated relations, cf. in particular J. Hall, Proc. Amer. Assoc., 1883, p. 66, and W. M. Davis, The folded Helderberg Limestones East of the Catskills, Bull. Mus. Comp. Zool. Cambridge, 1883, Geol., ser. I, pp. 311–329, pl. A local unconformity already disturbs the relations of the upper Silurian Niagara Group with the lower Silurian.

[2] H. S. Williams, The Recurrence of Faunas in the Devonian Rocks of New York, Proc. Amer. Assoc., 1881, XXX, pp. 186–191; another recurrence of the same fauna is even asserted to occur in the Utica slates; also by the same, On the Fossil Faunas of the Upper Devonian along the Meridian of 70° 30′, Bull. U. S. Geol. Surv., 1884, No. 3, pp. 55–86.

[3] J. M. Clarke, On the higher Devonian Faunas of Ontario County, New York; op. cit., 1885, No. 16, pp. 41–120, pl.

marine shells, fish remains, and terrestrial plants. Clarke found intercalated with these a bed of nodular limestone with Goniatites, which enables us to correlate this member with the base of the upper Devonian of Europe; and at the same time it corresponds precisely with the petroleum-bearing Domanik shales of the Petchora [1].

Thus the chronological equivalents of the Russian transgression on the other side of the Atlantic Ocean have now been determined.

But it is precisely these equivalents of the maximum of the Russian transgression, i. e. the rocks of the Hamilton group, which have been met with on the western border of the Canadian shield and in the valley of the Mackenzie, extending far beyond the region of the Silurian formations of the United States up to the shores of the Arctic Ocean (II, p. 38). We have seen that amongst all the fossils collected between the Clear-water in lat. 56° 30′ N. and the Arctic Ocean, Meek recognized none but species of the Hamilton group. Above the calcareous Hamilton beds strictly so called, lie petroleum-bearing shales with beds of *Styliola fissurella*, a continuation of the Genessee shale of the south, and the organic remains of these beds remain essentially the same through nearly thirty degrees of latitude, from Rock island, Illinois, up to the Arctic Ocean [2].

Nowhere within the vast region which extends from the Clear-water to the Arctic Ocean is the Silurian known to occur; future explorers may perhaps discover it. Yet it is hard to understand how deposits elsewhere of such wide extension, forming part of a flat-bedded series and lying near the Archaean foundation, should escape observation, and again, why the same members of the Devonian, and these only, should always have attracted the attention of the observer.

In the present state of our knowledge we must conclude that the Hamilton beds, together with the overlying Genessee shales, advance in a great transgression over the western part of the Canadian shield; thus they form the western glint and insert themselves on the north into the Silurian-Devonian-Carboniferous region which forms the Arctic archipelago. In what way these beds are continued within the zone of sandstone which lies in this region beneath the Carboniferous sandstone is at present unknown.

These transgressive deposits of western Canada are, as we have said, the chronological equivalents of the transgressive deposits of the Russian Devonian. *Thus we arrive at the conclusion that a very considerable extension of the Devonian seas took place simultaneously from the Ural over*

[1] The Naples shales occupy the lower part of the Portage Group; F. Roemer refers the Goniatite beds of Büdesheim and of Torbay in Devonshire to this horizon; Lethaea, 1880, I, pp. 50, 53; Clarke, tom. cit., pp. 38, 39, 49. *Cardiola retrostriata*, Buch, extends through the whole of the Hamilton group and attains its maximum in the Goniatite beds.

[2] F. B. Meek, Trans. Chicago Acad. Sci., 1868, I, p. 77.

the Russian plain towards the west and north-west, and from the Rocky mountains across the valley of the Mackenzie to the east. The correspondence extends so far that the Domanik shales on the upper Petchora and the contemporaneous Genessee shales on the Athabasca are both characterized by the presence of petroleum.

The positive phase in the middle of the Devonian system thus manifests itself on both sides of the Atlantic Ocean at the same time.

4. *The Carboniferous system.* In discussing the phenomena associated with the formation of the great coal deposits I shall again confine myself for the present to the North Atlantic region, using this term in the widest sense, to indicate that part of the northern temperate zone which extends from the Ural in the east to the Rocky mountains in the west or over nearly half a circle of latitude. In this region, throughout the whole of the Carboniferous, so striking a correspondence prevails between the most important members of the series on both sides of the Atlantic that we may venture to consider the European and American areas together, comparing them step by step.

(*a*) The sediments of this period begin for the most part with a sandstone deposit of variable thickness. In Scotland it is called the Calciferous sandstone, in Ireland the Coomhola grit, in eastern Canada the lower Coal-measures, in Pennsylvania, according to the nomenclature employed by Rogers, the Vespertine and Umbral series; towards the west these beds decrease in importance; in Ohio they are known as the Waverley sandstone. In Illinois, however, the clastic sediments derived from the land thin out, and dolomitic limestone with marine fossils takes their place; the series is then known as the Kinderhook group.

Just as the series thins out as it proceeds from east Canada and Virginia towards the west, so it does in Europe when traced from Great Britain to the east; and in the south of Russia there reappear in the lowest marine beds of the Carboniferous some of the characteristic marine fossils of the Kinderhook group of Illinois.

In Great Britain the remains of terrestrial plants, and in a few cases of marine animals, are interspersed in this lowest series. Kirkby has given an exact account of the succession in the Calciferous limestone of Fife in Scotland. Here the lowest part of the series is not exposed; nevertheless we are able to examine a thickness of more than 3,900 feet. Within the upper 3,400 feet—that is, the whole series with the exception of its lowest part—there are about fifty thin beds of coal three inches and upwards in thickness, many of them resting on beds of clay with Stigmaria, which are regarded by most observers as the original roots of the forest growth, or as a proof that the coal was formed *in situ*. Plant remains also occur scattered through the sandstone. In addition, there are not less than eighteen beds of shale or thin layers of limestone intercalated in this series

at various levels and containing marine shells. Thus, 2,280 feet below the upper limit of the Calciferous sandstone an Encrinite bed occurs with 35–40 species of marine shells, and numerous Crinoids, and this contains stems of Lepidodendron and Dadoxylon [1]. But if the underclay with Stigmaria is to be recognized as the original soil, then the conditions favourable to the growth of land or marsh plants must here have alternated often indeed with periods of occupation by the sea.

On the Atlantic coast of Ireland the thickness of this series amounts, according to Hull, to about 1,500 feet [2].

In New Brunswick and Nova Scotia, where the series attains a prodigious thickness, the occurrence of workable coal is well known, but intercalations of marine beds are absent. In the west, on the other hand, in Illinois, the Kinderhook group is formed chiefly of friable beds, often dolomitic, which, as we have seen, contain marine fossils [3].

In the Pyrenees and in Asturias the 'Marbre griotte' distinguished by its Goniatites must be assigned, according to Barrois, to the lowest parts of the Carboniferous system [4].

(*b*) Above this lowest division of the Carboniferous there lies, in Europe as in America, the *Carboniferous limestone*, which, by its abundance in all kinds of marine animals and by the great thickness it attains, indicates the prolonged existence of the open sea over the greater part of the region before us. We can scarcely otherwise represent the facts than by supposing that after the singular oscillations which took place in Scotland during the deposition of the Calciferous sandstone, just illustrated by an example, pelagic conditions were established far and wide.

In England, according to Hull, the Carboniferous limestone increases in importance towards the south-east; in Belgium it occurs with a thickness of 800 meters; it extends over a large part of Germany without acquiring any great thickness, and then broadens out in a great sheet over the Russian plain, extending far beyond the Ural and into the Arctic regions. It forms a large part of the surface of Ireland, attaining there a thickness of 2,500 to 3,000 feet, and it occurs in France as well as in Spain.

Across the Ocean it appears in eastern Canada, with intercalations of reddish shales accompanied by gypsum, an indication of interrupted

[1] J. W. Kirkby, On the Zones of Marine Fossils in the Calciferous Sandstone Series of Fife, Quart. Journ. Geol. Soc., 1880, XXXVI, pp. 559-590; also R. Etheridge, jun., On our present Knowledge of the Invertebrate Fauna of the Lower Carboniferous or Calciferous Sandstone series of the Edinburgh neighbourhood, op. cit., 1878, XXXIV, pp. 1–26, pl.

[2] E. Hull, Physical Geography and Geology of Ireland, 8vo, London, 1878, p. 31.

[3] A. H. Worthen, Geology of Illinois, 1868, III, p. 115 et passim.

[4] C. Barrois, Recherches sur les terrains anciens des Asturies et de la Galicie, Mém. Soc. Géol. Nord, Lille, 1882, I, pp. 570, 576, and 583 et passim; also Bol. Com. Mapa geol. España, 1881, VIII, pp. 131–155.

deposition and the temporary existence of evaporating lagoons[1]. It is absent in Virginia, where a great deposit of sandstone takes its place. Beyond this region to the west, on the other hand, it begins to increase again in thickness. In the south-west of Illinois it is 1,200 to 1,500 feet thick. From this we see that the Carboniferous limestone of the central part of the United States was separated from the Atlantic region by a deposit of sand, that is by a clastic zone occupying very nearly the site of the existing mountain chains of the east, and that consequently communication with the Carboniferous sea of Europe could only have taken place by a circuitous route. Nevertheless there is a close correspondence between the faunas of the two regions, and with the progress of investigation the number of identical species continually augments[2].

Several series have been distinguished in the Carboniferous limestone; by Hull and Worthen in America, and by Gosselet and Dupont in France and Belgium. De Koninck has made an attempt to compare these with one another, as well as with those of Russia[3].

(*c*) and (*d*) In Europe a stage now appears which has not been recorded in America; in typical localities it presents the character of a littoral formation with a mixture of terrestrial plants and marine shells. This is the *Culm* or the *Yoredale beds*. Its flora is widely distributed beyond the limits of Europe. The Culm occurs in Ireland and England, in Belgium, on the Rhine, in the Vosges, and in the Harz, and following the Variscan folds it extends, not indeed without interruption, but with constant characters, as far as Moravia. It is known in France, F. Roemer has shown that it occurs in Spain and Portugal, and Toula has discovered it in the western Balkans[4].

Some observers hold the opinion that close relations exist between the Culm and the *unproductive sandstone or Millstone grit*; a sandstone deposit which occurs in some regions in great thickness and is absent in others. Where the Culm is not present the unproductive sandstone rests directly on the Carboniferous limestone. From Hull's useful summary we see that the Millstone grit and beneath it the Yoredale beds attain the

[1] Dawson, Acadian Geology, in particular p. 278 et seq.

[2] e. g. S. G. Perceval, *Palaeacis cuneata*, Geol. Mag., 1876, 2nd ser., III, p. 267; Etheridge and Nicholson, On Palaeacis, Ann. Mag. Nat. Hist., 1878, 5th ser., I, p. 206 et seq.; G. A. Lebour, Note sur deux fossiles du Calcaire carbonifère de Northumberland, Ann. Soc. géol. Belg., Liège, 1876, III, p. 21 et seq.

[3] L. G. de Koninck, Note sur le *Spirifer Mosquensis*; Bull. Mus. Hist. nat. Belg., 1883, II, pp. 371-379.

[4] F. Roemer, Ueber das Vorkommen von Culm-Schichten mit *Posidonomya Becheri* auf dem Südabhange der Sierra Morena, Huelva, Zeitschr. deutsch. geol. Ges., 1872, XXIV, pp. 589-592; and by the same, Ueber das Vorkommen von Culme-Schichten mit *Posidonomya Becheri* in Portugal, tom. cit., 1876, XXVIII, pp. 354-360; F. Toula, Geologische Untersuchungen im westlichen Theile des Balkan, Sitz. k. Akad. Wiss. Wien, 1878, LXXVII, pp. 249-317, and in particular pp. 253 and 307.

greatest thickness in south Lancashire; indeed the first is estimated at 3,500 to 5,000 feet, the second at 2,000 to 4,000 feet. In Yorkshire, Derbyshire, and north Staffordshire the thickness is still considerable; then it diminishes in all directions somewhat rapidly, and only near Bristol rises again exceptionally to about 950 feet [1].

The unproductive sandstone reappears in Westphalia and there rests on the Culm; von Dechen gives confirmative evidence to show that these two deposits are difficult to distinguish, and several species of Culm plants appear in the unproductive sandstone [2].

Beyond the Ocean we see the unproductive sandstone, in Pennsylvania 1,000–1,500 feet thick, extending along the Appalachians towards Virginia and Tennessee, and at the same time increasing rapidly in thickness towards the west. The occurrence of the Carboniferous limestone in Europe as in America, succeeded in both regions by the unproductive sandstone, is so striking a fact that it was adduced by Dana as a conspicuous proof of the contemporaneity of the changes which have affected both hemispheres [3].

(*e*) We have now reached that series of deposits in which the greatest quantity of fossil fuel lies accumulated. Many unsolved problems are connected with the origin of the coal, and it will be necessary to enter into some detail.

Marine conditions are on the wane, but have by no means altogether disappeared. In the mighty deposits composed chiefly of sandstone and shale, that is, clastic sediments derived from the land, the coal beds as a rule are repeated one above the other a great number of times. The coal-field of Ostrau and Karwin in Moravia and Silesia includes two series of coal-bearing formations of different age. Leaving out of account the beds under 15 cm. in thickness, the lower divisions contain 179 coal beds in a thickness of 3,793 meters; and the upper division, which is 415 meters thick, includes thirty-nine coal beds; or both together 218 coal beds in a formation 4,208 meters thick, and on an average one meter of coal to twenty-eight meters of sandstone and shale [4].

In contrast to this we see that in central Bohemia the coal-bearing formations contain coal only in their lowest part, and the number of beds

[1] E. Hull, On the Upper Limit of the essentially Marine Beds of the Carboniferous Group of the British Isles and adjoining Continental Districts; Quart. Journ. Geol. Soc., 1877, XXXIII, pp. 613–650.

[2] Von Dechen, Erläuterungen zur geologischen Karte der Rheinprovinz und der Provinz Westfalen, II, 1884, p. 220; D. Stur, Verh. k. k. geol. Reichs., 1876, p. 266. Also Hull (tom. cit., p. 619) points out similar relations between the Culm and the sterile sandstone.

[3] J. D. Dana, Manual of Geology, 2nd ed., 1875, p. 394; also H. Martin Chance, The Millstone Grit in England and Pennsylvania, Am. Journ. Sci., 1881, XXI, p. 134.

[4] Monographie des Ostrau-Karwiner Steinkohlen-Revieres, herausgegeben und bearbeitet vom Berg.-Hütt. Ver., Mähr.-Ostrau, 4to, Teschen, 1885, Geognostischer Theil von W. Jičinsky, p. 18.

over 15 cm. thick hardly amounts to more than eight or ten, of which the lowest it is true attain an imposing thickness. These measures are followed by a very great accumulation of unproductive sandstone and shales, and then by upper Coal-measures, perhaps of Permian age [1].

The Coal-measures of Moravia and Silesia rest conformably on the Culm, and a part of the Culm flora extends into their lowest beds; the Coal-measures of central Bohemia, on the other hand, rest in transgression on Archaean and Silurian rocks. The first region contains marine intercalations, the second does not. This is the first example which shows how manifold were the conditions under which the Coal-measures were produced.

Marine beds are not seldom intercalated with the Coal-measures. It has often been maintained that the repeated formation of coal beds has been caused by so many oscillations of the solid land. In England especially insistence has been laid on the fact that below most of the coal beds a clay, the 'underclay,' is present, filled with the still rooted trunks of the plants which formed the coal, as we have already mentioned in speaking of the Calciferous sandstone of Fife: the coal must thus have been formed in place, and each particular bed indicates the occurrence of a fresh land surface or marsh, on which a new forest growth arose. We will not now inquire how often the whole solid crust of the planet must have been moved upwards and downwards in order to form such series of beds, but will first attempt, beginning in the west, to obtain a general survey of the various types of development among the Coal-measures. It will then be seen that above the marine fauna of the Carboniferous limestone mentioned above there exists in the Culm and in the intervening beds another, although not sharply differentiated, marine fauna, and that this is followed later by yet another fauna, the marine fauna of the upper Carboniferous or that of the Fusulina limestone.

In Utah and Nevada, the most westerly part of the regions considered here, the whole Carboniferous is represented by marine deposits which attain an extraordinary thickness; Clarence King gives for the Wahsatch limestone, which contains lower Carboniferous fossils and perhaps extends down into the Devonian, a thickness of 7,000 feet in the Wahsatch mountains; for the Weber quartzite resting on the limestone 6,000 feet, and for the upper Carboniferous limestone 2,000 feet. The figures given for central Nevada are not quite so large. It is worthy of note that in Nevada, in the midst of masses of marine limestone, amongst corals and brachiopods, Walcott has discovered two species of air-breathing gastropods which must evidently have been borne in from a distance [2].

[1] M. V. Lipold, Das Steinkohlengebiet im nordwestlichen Theile des Prager Kreises in Böhmen; Jahrb. k. k. geol. Reichs., 1861 and 1862, XII, pp. 431–525, pl.

[2] *Physa prisca, Zaptychius carbonaria.* Walcott, Palaeontology of the Eureka District, 1884, VIII, pp. 262, 263.

To the east, on the outer border of the Rocky mountains and as far as the Black hills, Dakota, the thickness greatly decreases; but the deposits are all marine.

Still further to the east beyond the prairies, the Coal-measures begin to make their appearance. At first, in eastern Nebraska, the coal beds according to Meek are certainly very rare, small and scarcely workable; beds of marine Fusulina limestone alternate with beds of shale which include the scattered remains of half-decayed plants and some tree stems [1].

Beyond the Missouri in Iowa there are many workable seams, but always associated with the marine limestone. The Coal-measures rest on the lower Carboniferous limestone. In the south-east, where there was open sea, the Carboniferous limestone is everywhere visible beneath the Coal-measures, but towards the north, in Iowa and Illinois, the latter extend far beyond the Carboniferous limestone, and often rest on Devonian or Silurian beds. Towards the Appalachians the Carboniferous limestone is represented, as we have seen, by sandstone, conglomerate and shales. During this transgression

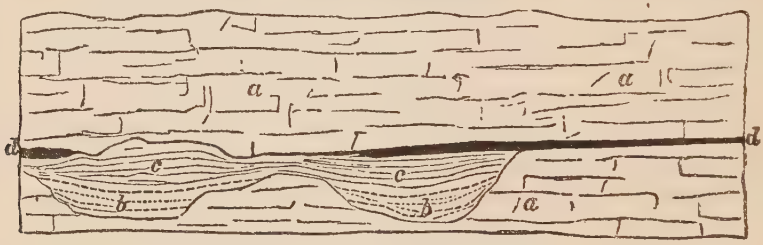


FIG. 25. *Section near Iowa city*, after J. Hall.
a, Devonian limestone; *b*, coarse sandstone in wavy layers; *c*, grey and greenish clay; *d*, small seams of coal, the lower part shaly, containing fish teeth.

it happened that the transgressive coal-bearing sediments penetrated from above into cavities of the Devonian limestone, and formed within these cavities little stratified deposits which even contain fish remains, and in one place a little bed of coal. These facts, which have been described by J. Hall, have an important bearing on explanations to follow [2] (Fig. 25).

The Coal-measures of this region are distinguished by the frequent intercalations mentioned above of fossiliferous marine beds between the coal seams; Worthen describes a section at New Haven on the lower Wabash, Illinois, in which twenty fossiliferous marine intercalations and sixteen coal

[1] F. B. Meek, Report on the Palaeontology of East Nebraska (in Hayden, Rep. U. S. Geol. Surv. Nebraska), 4to, Washington, 1872, p. 134 et passim.

[2] J. Hall, in Hall and Whitney, Report on the Geological Survey of the State of Iowa, 8to, 1858, pp. 117, 130, 131. Richthofen saw the same thing in Shantung and Shansi; cf. his China, II, pp. 203, 411, 437, 718; and in Newfoundland Carboniferous fossils are found in the cavities of the Silurian limestone; Murray and Howley, Geological Report, Newfoundland, London, 1881, p. 333, note.

beds occur in alternation. Some of the marine beds attain a thickness of thirty-five feet [1].

These marine intercalations continue to Ohio and west Virginia; in Pennsylvania they come to an end. They are also absent in eastern Canada. In the section of the south Joggins, on the northern arm of Fundy bay, which was studied by Logan, Lyell, and Dawson, the Carboniferous formation is exposed along the coast; there are eighty-one beds of coal, most of them resting upon underclay. We meet with stems of trees standing upright, reptiles in hollow tree-trunks, air-breathing mollusca, remains of fishes also, but no marine intercalations [2].

In continuing this rapid survey of Europe we must now distinguish two groups of Coal-measures. The first belongs to the outer border of the Armorican and Variscan chains, or lies to the north of this border. It comprises all the coal-fields of the British isles and of the north of France, next those of Belgium and Westphalia, and then, after a long interval, those of upper Silesia and Moravia. The second group lies south of the first; the coal-fields on the Saar and in central Bohemia, and that of Schatzlar-Waldenburg, belong to it. In the first group marine intercalations are known to occur, in the second there are none or at most feeble indications.

Where the first group forms a part of the border of the folded ranges it rests conformably on the next older deposits. The second group lies transgressively on various rocks. This at least appears to be the rule from Moravia onwards as far as the Rhine.

The numerous isolated basins which contain the rich Coal-measures of the British isles are probably only the remains of a once continuous formation, broken up by denudation and preserved owing to their tectonic position. In the important coal-fields of the south-west of England, i. e. those of South Wales, the Forest of Dean, and Bristol, the original continuity may be most clearly recognized. The coal-fields of Coalbrookdale, south Staffordshire, and Warwickshire are still perhaps connected underground. The coal-fields of Ireland and of the great trough of Scotland may also be regarded as parts of a single sheet. At the same time a very great degree of variability characterizes the thickness of the underlying coal-bearing sandstone, as well as the nature of the overlying beds. The coal-field of south Staffordshire rests unconformably on the upper Silurian [3].

Marine intercalations are found only in the lower parts of the Coal-measures; higher up they become rare, of trifling thickness, and present

[1] A. H. Worthen, Geological Survey of Illinois, 8vo, Boston, 1875, VI, p. 2–5.

[2] Dawson, Acadian Geology, pp. 150–218. The whole thickness is quoted on Logan's authority at 14,570 feet, but it is doubtful whether the uppermost of these beds do not belong to the Permian period; Dawson, Quart. Journ. Geol. Soc. 1874, XXX, p. 209.

[3] A. C. Ramsay, The Physical Geology and Geography of Great Britain, 5th ed., 8vo, London, 1878, pp. 119–128.

a purely littoral character; still higher they disappear altogether. In a general account of these intercalations by Hull, the lower subdivisions are spoken of as the *Gannister beds*[1].

The Gannister beds, characterized by the presence of marine fossils, are present in all the Irish coal-fields, with the exception of the Ballycastle coal-field in Antrim, which belongs to a still lower horizon: they also occur in Scotland, and in the various basins in England, whence they are continued into the continent. The same marine intercalations are found in the Coal-measures of the north of France, as for instance near Auchy-au-Bois, and at several localities in Belgium. In the basin of Charleroi the gaping valves of a Mytilus still attached in pairs occur in great numbers. This is precisely what may be seen on a modern beach when mussels have quietly decomposed: the adductor muscles give way first, then the shell flies open. These beds thus mark undisturbed deposition[2].

In the Coal-measures of Westphalia there are numerous intercalations containing shells; the lower of these are of purely marine origin, but higher up they contain only species of the genus Anthracosia, the marine nature of which is, to say the least, doubtful. Von Dechen has given the complete succession of these beds[3].

The presence of marine intercalations in the Coal-measures of upper Silesia was first discovered by F. Roemer in 1863, and in 1870 he compared this remarkable series with the Gannister beds or 'Pennystone' of Coalbrookdale and Carluke in Scotland. Kosmann has shown that they repeat themselves at definite horizons and may render great service in determining the succession of the coal beds. The shell-bearing beds are partly of marine origin, doubtless indeed littoral, and contain such genera as Phillipsia, Bellerophon and Productus; others exhibit limnic characters, and these contain Anthracosia and Modiola[4].

[1] Hull, Upper Limit, &c., p. 616 et seq.

[2] C. Barrois, Notice sur la faune marine du terrain houiller du bassin septentrional de la France, Bull. Soc. géol. de Fr., 3e sér., II, 1873–1874, pp. 223–226; Gosselet, Esquisse géologique du Nord de la France, 8vo, Lille, 1880, p. 149 et seq.; Briart et Cornet, Notice sur la position stratigraphique des lits coquilliers dans le terrain houiller du Hainaut, Bull. Acad. Roy. Belg., 1872, 2e sér., XXXIII, pp. 21–31; R. Malherbe, Des horizons coquilliers du système houiller de Liège, Ann. Soc. Géol. Belg., Liège, 1876, III, p. lxvii et seq. Beds are here considered which, judging from the character of the fossil shells, are not indubitably of marine origin; the gaping Mytilus are described by C. Blanchard and J. Smeysters, Note sur quelques fossiles rencontrés dans le système houiller de Charleroi, op. cit., 1879–1880, VII, Mém., p. 15.

[3] H. von Dechen, Erläuterungen zur geologischen Karte der Rheinprovinz, II, p. 247 et seq.

[4] F. Roemer, Ueber eine marine Conchylienfauna im productiven Steinkohlengebirge Oberschlesiens, Zeitschr. deutsch. geol. Ges., 1863, XV, pp. 567–606; by the same, Geologie von Oberschlesien, 8vo, 1870, in particular pp. 94, 95; Weiss, Zeitschr. deutsch. geol. Ges., 1879, XXXI, p. 219, &c.; Kosmann, Die neueren geognostischen und

The investigations pursued for many years by D. Stur, on the prolongations of the upper Silesian coal-field into Austria at Ostrau and Karwin, have established the following facts. The Coal-measures lie conformably on the Culm, which contains terrestrial plants and at the same time marine animals, as in Nassau. A part of the flora of the Culm ascends into the lower division of the coal-bearing beds, and forms together with additional species the upper Culm flora, the zone of *Sphenophyllum tenerrimum*, or the *Ostrau beds*. This zone includes five groups of coal seams; in the three lower of these marine intercalations occur similar to those observed by F. Roemer in upper Silesia. The most important of these lies between the third and fourth coal-bearing groups; Stur likewise believes that it represents the English Gannister. In the fourth and fifth groups we have only the genus Modiola, then Anthracosia in great quantity, and finally Eurypterus, Cypris, and Planorbis. The marine character has disappeared.

Now follows a higher division of the coal-bearing formation with a new flora, the *Schatzlar beds*; in these, marine intercalations are unknown[1].

These facts show that throughout the central part of the United States, from Indiana and Iowa to western Pennsylvania, frequent marine intercalations occur between the coal beds, and these only cease in those eastern regions where, as in the Alleghanies, the underlying Carboniferous limestone is also replaced by sandstone and shales; or where, as in New Brunswick, the proximity of the shore is revealed by interbedded gypsiferous marls. The intercalations are more considerable in the lower parts of the coal-bearing formations, and there the marine origin is more clearly manifest, while towards the upper part littoral characters become increasingly evident and the intercalations are in general of slight importance.

Similar marine intercalations are present in the Coal-measures of Scotland, Ireland, England, the north of France, Belgium, Westphalia, upper Silesia, and north Moravia. Here also the lower beds contain a fauna certainly marine; these are followed, either immediately or after some previous alternations, by littoral mollusca or by mollusca of uncertain, perhaps of lacustrine origin, such as the Anthracosia; still higher in the series, however, these intercalations are wholly absent.

Notwithstanding this apparent correspondence the intercalations in Europe and America are not of the same age. Those of Europe are the Gannister beds, which are closely allied by their fauna to the lower Carboniferous; certain new species contribute an additional feature and the more important groups characteristic of the open sea are usually absent.

paläontologischen Aufschlüsse auf der Königsgrube bei Königshütte, Ober-Schlesien; Zeitschr. f. Berg.-, Hütt.-, Salin., Berlin, 1880, XXVIII, pp. 305–340, maps.

[1] D. Stur, Die Culmflora der Ostrauer und Waldenburger Schichten; Abh. k. k. geol. Reichs., 1877, VIII, p. 423 et seq. According to Stur the marine intercalations here belong to Coal-measures lower in the series than those of Westphalia and Belgium, which he assigns to the Schatzlar group.

The American intercalations, on the other hand, contain the fauna of the upper Carboniferous, that is of the Fusulina limestone.

The case is otherwise in southern Europe.

In Asturias, according to Barrois, the Carboniferous limestone is succeeded by beds containing the Culm flora, these by an alternating series of beds, some containing plants and others marine mollusca, which ascend up to the level of the intercalations met with in America on the horizon of the Fusulina limestone, as is shown by the identity of a large number of species [1].

Still more remarkable are the facts observed in the southern Alps. On the Auernig and the Kronalp, near Pontafel in Carinthia, we find a frequent alternation of yellow sandstone, which contains plants belonging to the uppermost Carboniferous flora, and of dark limestone filled with Fusulina and characterized by a marine fauna, which may be correlated with that of the upper Carboniferous intercalations of America. The sandstone is associated with beds of quartzose conglomerate; sometimes a few isolated marine shells are found along with its plant remains [2].

There is thus a complete correspondence between these sections in Carinthia and those of the coal-fields of Illinois and Iowa. In Carinthia the coal beds are represented by plant-bearing sandstone, but the alternating facies is present in one locality as in the other.

In the south of Russia workable measures crop out on the Doneta. Some difference of opinion prevails as to the succession of the strata in the principal region, but on the north border of the basin near Kaluga, Tula, and south of Rjasan, the facts have been completely elucidated by the investigations of A. Struve [3].

[1] Barrois, Asturies, pp. 582, 593, &c.

[2] I have frequently stayed for a considerable time in the Kühweger and Watschiger Hütten and the Hütte am Ofen in order to gain a knowledge of these beds. In 1879 I traced the succession in the Krone; it appeared that the little patch of Coal-measures with Productus, which is also mentioned by Stache, is separated from the series by a dislocation. It lies higher than the yellow sandstone beds, which are distinguished by large specimens of Spirophyton, and shows an alternation of sandstone and quartzose conglomerates repeated four or five times, and of bluish-black Fusulina limestone. Plant remains occur in the sandstone, which D. Stur has been kind enough to determine; they all belong to the highest division of the Carboniferous; among them are *Annularia sphenophylloides* and *Pecopteris longifolia*. An occasional brachiopod may be found with them in the sandstone. In the Fusulina limestone, on the other hand, we meet with Phillipsia, Conocardium, &c. Most striking is a highly ornamented gastropod, probably *Naticopsis nodosa*, Meek and Worthen, or the variety *N. Wortheni*, Barrois. Stache many years ago recognized the American character of the beds in certain localities of the southern Alps; that he should take them for Permian was intelligible at a time when the limit of the Permian had been placed too low even in the American localities.

[3] A. Struve, Ueber die Schichtenfolge in den Carbonablagerungen des südlichen Theiles des Moskauer Kohlenbeckens; Mém. Acad. Imp. Sci. Saint-Pétersb., 1886, XXXIV, No. 6, 106 pp., map. The highly important distinction between the beds with *Spirifera mosquensis* (Fusulina limestone) and those with *Productus giganteus* (upper

It may be well to recall, however, before considering this district, that very different effects may be produced by the same cause, according as it acts in the neighbourhood of the shore or at a point some distance from it. In the proximity of the land the clastic sediments may attain a thickness so great as to bring them nearly to the surface of the sea, but further away an accumulation on a scale equally grand is not to be expected, but only a thin calcareous deposit. Further, a positive displacement, so trifling that the growth of the clastic sediments is able to keep pace with it, may give rise to a tract of marshy land always advancing both inland and seawards, while at the same time in the open sea the same displacement will merely bring about an increase in depth.

South of Moscow we again encounter the Fusulina limestone, but without intercalated coal seams or plant-bearing beds. Beneath it lies marine limestone with *Productus giganteus*, the highest horizon of the Carboniferous limestone. Towards the base this marine stage includes two beds of limestone containing Stigmaria and occasionally passing into sand and clay with thin beds of coal. Beneath these lie the workable measures, and beneath the measures, marine limestone beds, in their lowest part containing, as we have already seen, a few fossils of the Kinderhook group of Illinois.

Thus in Russia also the alternation of marine beds and Coal-measures is not wanting. The alternation, however, is less frequently repeated; it does not occur except in the lower horizons, far below the Fusulina limestone.

From these observations it appears that this kind of alternation is very characteristic of the Coal-measures of the Carboniferous system. We see it in the Calciferous sandstone of Fife, beneath the Carboniferous limestone; then in the Gannister beds overlying the Carboniferous limestone and extending from England as far as Moravia; finally, in the upper Carboniferous horizon of the Fusulina limestone in the United States, probably in Spain, and certainly in Carinthia, where the coal beds are represented by plant-bearing sandstone.

Far away from the regions considered here, in the coal-fields of north China, Richthofen has met with the same intercalations of marine beds; and there also the terrigenous clay of the coal-bearing series unconformably overlaps the Carboniferous limestone, and, as in Iowa, fills the cavities which have been excavated in the limestone by subaerial denudation; in south China, however, marine beds of the upper Carboniferous rest directly on the Coal-measures [1].

Carboniferous limestone) is also to be found in Koninck, Bull. Mus. Belg., 1883, II, p. 371 et seq. In the lowest beds of the Carboniferous limestone of Russia, Struve identifies several species as occurring in the American Kinderhook group. On the Russian plant remains see Stur, Verh. k. k. geol. Reichs., 1878, pp. 219–224.

[1] F. von Richthofen, China, II, pp. 205, 717, 782 et passim; p. 203, figure which shows the intrusion of Carboniferous clay into the cavities of the underlying limestone. Cf. note 2 on p. 238.

Although many thousands of men work day and night in our Coal-measures, and although many acute observers are led by their profession to make the study of these deposits the business of their life, yet the mode of formation of the coal beds is still far from being satisfactorily explained.

In England, geologists, as we have observed, lay great stress on the underclay with its Stigmaria, which they regard as the soil of a marshy forest, possibly growing out towards the sea, like the mangrove swamps of the present day; they take the Stigmaria for the roots, and point to the upright trunks of trees, three to four meters or more in height, which here and there may be seen in the sandstone standing above the coal. The coal itself must consequently have been formed in the place where it is found, and lies at the foot of the trunks and over the tangle of roots, like the litter of an existing forest.

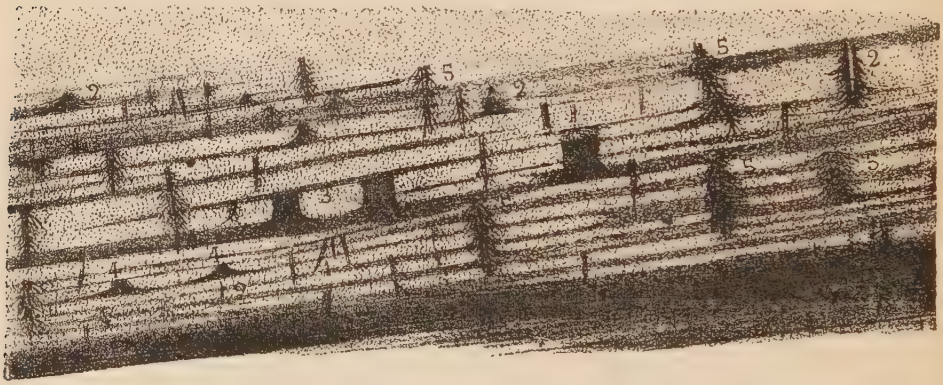


FIG. 26. *Fossil Forests of the Carboniferous Period.* At Trève, near Saint-Étienne, after Grand'Eury. Vertical height about 12 meters.

1. Calamites; 2. Psaronius; 3. Sigillaria; 4. Cordaites; 5. Calamodendron.

But the upright trunks prove that the sandstone cannot have been slowly deposited. Later on we shall point out that on the shores of the North sea peat bogs are to be seen lying some feet below the level of mean tide with the stumps of trees rising out of them; further, that sand dunes advancing inland, press down the peat below the level of the sea, and that in the sand of the dunes, so long as it covers the peat, the trunks of the buried forest may be seen, standing upright or more or less inclined. Forests thus overwhelmed by the action of the wind were observed in the Bermudas by the members of the *Challenger* expedition; the trees are buried in fine calcareous sand, which hardens to a friable rock and encloses the remains of the trunks still standing erect. A slow oscillation of the strand-line would never bring about this result, the trunks would decay and disappear[1]. In some cases the phenomenon has been explained by

[1] Thomson and Murray, Narrative, I, p. 141, fig. 55; p. 142, fig. 56. It has been supposed that the trunks had placed themselves vertically while floating and had

supposing that as the sediment grew upwards, the stems of the plants gave off new roots laterally, but even in this case the whole thickness of the sediment in question must have been deposited within the lifetime of these stems. The sketches of the sections to be seen in the open quarries at Saint-Étienne and published by Grand'Eury show clearly how the vegetation follows the deposition, and how fresh individuals again and again appear in the new beds. It is true Grand'Eury expressly points out that every considerable growth of trees or roots is cut off above by a 'dessolarde,' i. e. as though shaved off by a plane, above which the next bed begins. Although the succession of the forests is so clearly displayed in the basin of the Loire, yet Grand'Eury has been led by the consideration of the razed-off surfaces, and particularly by a thorough study of the process of vegetable decomposition, to return to the view that the coal beds have not grown in place, but are the remains of decaying plants transported by water, and deposited in stratified beds one above the other [1].

Let us now glance once more at Fig. 25, p. 238, which represents the intrusion of Carboniferous sediments into a hollow of the Devonian limestone. There is first a deposit of clay with fish teeth, and above this a thin layer of coal; but we can only account for the formation of the coal by supposing that the whole cavity was once filled with muddy water containing decomposing vegetable matter in suspension which afterwards collected at the top of the cavity.

It is definitely asserted that in Illinois the coal beds do not rest upon underclay, but directly on shale or limestone; in these cases the transport of vegetable matter from some other locality must be admitted, and we know that in Nebraska these coal beds pass into beds of shale, through which only isolated fragments of vegetable débris are strewn [2].

There appears to be no doubt that thick beds of coal may sometimes split up into a number of smaller seams, which become separated further and further from one another by the thickening out of intercalated wedges of sterile rock.

In England several examples of this are known. Jukes has shown that in south Staffordshire the main coal bed, twenty-five feet in thickness, splits towards the north into nine seams, in such a manner that the sum of the seams and the intervening beds amounts to 390 feet. One thin shaly

then sunk vertically into the sediments, but this can hardly be true of whole forests; H. Fayol, Sur l'origine des troncs d'arbres fossiles perpendiculaires aux strates du terrain houiller, Compt. Rend., 1881, XCIII, pp. 160–163.

[1] F. C. Grand'Eury, Flore carbonifère du département de la Loire et du centre de la France, 4to, Paris, 1877, with atlas, pl. xxxiv, and Mémoire sur la formation de la houille, Ann. Mines, 1882, 8e sér., Mémoires, I, pp. 99–292, pl.; Dessolarde, pl. iii, fig. 6.

[2] A. H. Worthen, Geological Survey of Illinois, 1886, I, p. 70.

parting swells out within a distance of one mile into a wedge of unproductive measures 128 feet thick [1].

The great bed of Commentry (Allier) divides, according to Fayol, into six smaller seams which diverge farther and farther apart [2].

In the United States this question has given rise to very searching discussions. Andrews having maintained the uniform and continuous extension of the coal beds, it was shown by Newberry and Stevenson that, as a matter of fact, certain thick beds, owing to the swelling out of the intervening masses, are divided towards the middle of the original basin into several seams sometimes widely separated from one another. At the period of the upper Coal-measures, i. e. during the formation of the chief beds of coal, the eastern region of North America had already been divided by the anticlinal of Cincinnati (I, p. 557) into two basins which unite towards the south-west, so that Ohio, Pennsylvania, and west Virginia show a certain independence in respect to Iowa, Illinois, and the western regions, notwithstanding the correspondence in character otherwise so marked between the marine intercalations. It is towards the bottom of these two basins that the splitting up of certain of the marine seams appears to become complete [3].

'I am therefore compelled to believe,' writes Stevenson, 'that all the coals of the upper coal group are offshoots from one continuous marsh which existed from the beginning of the aera to its close, and which in its full extent is now known as the Pittsburg coal seam. During the whole time of the formation of the upper coal group the general condition was that of regular subsidence interrupted by longer or shorter intervals of repose. During the time of subsidence the marsh advanced up the side of the trough, as new land was continually becoming fitted for its support. During repose, deltas were formed in the bay, and the marsh pushed outward over the newly formed land.'

In this way, step by step, we separate out the three elements which take part in the formation of the coal-bearing sediments: these are (1) the marine beds—as a rule limestones, sometimes shales; the limestones of

[1] J. Beete Jukes, The South Staffordshire Coal-field, 2nd ed., 8vo, London, 1859, p. 87.

[2] A. de Lapparent, Traité de géologie, 2e éd., 8vo, Paris, 1885, p. 841.

[3] E. B. Andrews, Some Conclusions, Theoretical and Practical, Rep. Geol. Surv. Ohio, I, 8vo, Columbus, 1873, pp. 345–364; and by the same, On the Parallelism of Coal Seams, Am. Journ. Sci., 1874, 3rd ser., VIII, pp. 56–59; J. S. Newberry, On the Parallelism of Coal Seams, op. cit., 1874, 3rd ser., VII, pp. 367–369; J. J. Stevenson, The Upper Coal Measures west of the Alleghany Mountains, Ann. Lyc. Nat. Hist. N. York, 1873, X, pp. 226–252; and Note on the Coals of the Kanawha Valley, West Virginia, tom. cit., pp. 271–277, map; by the same, On the alleged Parallelism of Coal Beds, Proc. Am. Phil. Soc. Philadelphia, 1874, XIV, pp. 283–295. Long ago the same question was also eagerly discussed by distinguished American geologists; Rogers insisted on the splitting of the coal seams, Lesquereux on their formation in place, a theory which is evidently very inconsistent with the splitting.

moderate thickness persistent over wide areas, the result of slow continuous formation; (2) the beds of sandstones or shales—swelling out from paper-thin partings into great wedge-like masses, sometimes showing signs of a rapid deposition, such as oblique lamination or pockets filled with sand; (3) the coal beds—some of them thick deposits formed off the shore, splitting up towards the sea through the thickening out of the unproductive measures in the manner just described.

A correct conception of the facts long ago led Naumann to distinguish *limnic* and *paralic* measures, namely those which indicate marshy surroundings and those which point to marine conditions. Naumann even at that early time recognized that in the paralic regions numerous coal beds occur, but that they are as a rule of trifling thickness [1]. In like manner Gümbel distinguishes *autochthonous* measures, i. e. those which have been formed in place; and *allochthonous* measures, those which have been produced by drifted plant remains deposited in water [2].

We must admit, as is shown by the observations on the splitting of coal seams, that a thick limnic bed may subdivide into a number of paralic seams, the latter being certainly allochthonous. The widely extended beds which occur in frequent alternation with marine sediments in the central part of the United States belong to the paralic allochthonous formations. It must be left to later investigations to decide whether the abundant rainfall which perhaps characterized this period may not have brought about the accumulation of vegetable detritus in shallow ill-defined lagoons, and so produced the limnic beds (the view advocated by Grand'Eury and shared by Saporta [3]), or whether these beds may not after all be autochthonous, formed from plants the roots of which still remain in place.

It is certain that during the Coal period the moist land was thickly overgrown by a peculiar vegetation. The sudd of the Nile and the floating mattresses of plants of the Mexican lakes bear witness to the luxuriant development which may be attained by vegetation in a warm climate and in fresh water. When Cameron was searching in 1874 for the outlet of lake Tanganyika in the direction of the Lukuga, he travelled some miles down the river until the masses of floating plants made further progress impossible. The lake rose, and in 1876 Stanley received from all sides accounts of the occurrence. Palms, which in 1871 stood on the shore at Ujiji, were now standing out in the lake 100 feet from shore. 'The whole country will be inundated and nothing will be left except the tops of the great mountains,' said one of the native chiefs. Stanley embarked on the Lualaba, and describes the gradual hemming in of the river by the

[1] C. F. Naumann, Lehrbuch der Geognosie, 2. Aufl., Leipzig, 1862, II, p. 584.

[2] C. W. von Gümbel, Beiträge zur Kenntniss der Texturverhältnisse der Mineralkohlen; Sitz. k. bayr. Akad. München, 1883, pp. 111–216, pl.

[3] G. de Saporta, Bull. Soc. géol. de Fr., 1887, 3e sér., V, p. 383.

floating masses of plants, which approached from right and left, until they finally closed up round tranquil standing water. The depth of the water at the wall-like barrier, which was covered with high reeds, was seven to eleven feet. Pressing forward about twenty yards into the reeds he found impassable mud, black as pitch, and seething with animal life. He foretold the bursting of the dam. 'The accumulated waters of over a hundred rivers will sweep through the ancient gap with the force of a cataclysm, bearing away on the flood all the deposits of organic débris at present in the Lukuga creek.' This rupture occurred no later than 1878. Shortly after, the missionary Hore descended the current of the Lukuga, now set free, which was then extremely rapid. When Lenz visited Tanganyika in 1886 the lake had fallen fifteen feet. Relict strand-lines were seen between Ujiji and the lake, and in many other places [1].

On the leeward side of the lesser Antilles, Agassiz met with leaves, pieces of sugar-cane, and fragments of decomposing plants, ten to fifteen miles from the land, and at a depth of more than 1,000 fathoms ; and near some of the Polynesian islands the *Challenger* sometimes dredged a leaf or a branch from more than 1,400 fathoms. Notwithstanding these instances, the wide dispersal of decomposed plant remains in sufficient quantity to form seams of coal still remains a marvellous phenomenon.

As regards the questions under consideration, it is clear from what has been said that we are scarcely justified in assuming that every marine intercalation which occurs between paralic measures represents an oscillation of the strand. The splitting of the limnic coal definitely excludes such a supposition. Only where beds certainly autochthonous alternate with marine beds, or where littoral inundation manifests itself over a wide area, can oscillation be regarded as proved.

When the paralic coal seams alternate frequently with marine beds, as for instance in Illinois, and split up still further till they pass into unworkable beds of vegetable detritus, then they approach more and more closely to the character of those shaly partings which, repeated often hundreds of times, divide our limestones into definite beds. Since these paralic formations are known, both beneath the great mass of the stratified Carboniferous limestone as well as above it, the question arises whether the clayey partings between the bedding planes which determine the stratification of the Carboniferous limestone itself may not have a similar origin.

The processes which we have been tracing in their effects took place very quietly, and were prolonged over periods of extraordinary duration. Still it is incontestable that in the middle of the Coal-measure period a number of great folded ranges were both elevated and worn down by

[1] H. M. Stanley, Through the Dark Continent, London, 1878; O. Lenz, Brief, Mitth. k. k. Geogr. Ges., 1887, XXX, p. 98.

denudation, and the younger measures passed in transgression over the abraded surfaces of the folds into which the earlier measures had been thrown. This is the case not only in Europe, but in all likelihood in Nova Scotia also [1]. In China, the folds of the Tsin-ling-shan involve the Carboniferous limestone, but on their denuded surface Richthofen encountered, at a great height, transgressive Coal-measures.

5. *The Permian system.* It is difficult to form any conception of the protracted period which would be necessary to accomplish the foldings and the erosions of the Carboniferous period. The magnitude of the erosion appears to its full extent when we take into account the Permian formation, during the deposition of which the sea again returned over regions it had previously abandoned.

Let us first consider Bohemia.

In the region of lower Silesia and Bohemia, according to Schütze's investigations, the complete series of the Coal-measures is represented, from the Culm to the Rothliegende. Five successive floras may be distinguished, united it is true by only a few species in common. The Waldenburg group at the base, approximately on the horizon of the marine intercalations of upper Silesia, contains fishes, Estheria, and possibly Modiola. But we can hardly regard this as representing the Gannister beds, elsewhere of such wide distribution. A good deal of conglomerate is intercalated with the beds [2].

In central Bohemia, and thence beyond Pilsen and Merschan, the Carboniferous lies horizontal and unconformable on the edges of the Silurian system. The latter, together with the associated subdivisions of the Devonian, was already faulted down, and doubtless completely separated from the other Silurian and Devonian ranges, at the time when the Coal-measures were formed over its surface. Here, as we have seen, some basal beds of the Coal-measures occur, which sometimes adapt themselves completely to the slight inequalities of the older rocks lying beneath them; these are followed by a great thickness of unproductive clastic rock, and above this come the uppermost measures, perhaps of lower Permian age, and the sandstone of the Rothliegende.

The Carboniferous mantle of central Bohemia dips to the north-west under the Rothliegende, and its termination is not visible. To the south-east, however, it is broken up by erosion into larger or smaller outliers, and over considerable areas has been entirely destroyed.

This limnic transgression of the Carboniferous, however, extended

[1] J. W. Dawson, On the Upper Coal-Formation of Eastern Nova Scotia and Prince Edward Island in its relation to the Permian; Quart. Journ. Geol. Soc., 1874, XXX, pp. 209–219.

[2] A. Schütze, Geognostische Darstellung des niederschles.-böhmischen Steinkohlenbeckens; Abh. z. Specialkarte v. Preuss., 1882, III, p. 19.

further and further over Bohemia, first filling up the hollows and then gradually levelling down the land itself. Hence we see isolated patches of the uppermost Coal-measures preserved in the marginal fractures towards Moravia and Bavaria, while they have been entirely swept away from the higher parts of the Bohemian mass. The transgression continued during the formation of the last beds of coal and into the Rothliegende. Hence a little isolated patch of Permian coal-measures still lies near Budweis in the midst of the Archaean region, and the remains of the denuded covering of Rothliegende crop out along the marginal fractures to the south-west as far as Regensburg, and to the south-east as far as Zöbing, near Krems.

The sea, however, did not follow these transgressions. They recall in a striking manner the ridging upwards of the borders of the Pittsburg marsh during the positive phase of the sea as conceived by Stevenson. To me also it is difficult to imagine the progress of these limnic transgressions without a simultaneous rise of the strand. They are everywhere represented in central Europe, first by the upper Coal-measures of the Carboniferous (Radowenz or upper Ottweil group), then by the Permian measures, and finally by the widely distributed Rothliegende sandstone and the accompanying conglomerates. This sandstone also extends far over the Russian plain, here and there accompanied by gypsum or rock-salt. Finally the positive influence became so preponderant that the sea reappeared over a considerable part of central Europe. This was the period of the Zechstein with its impoverished marine fauna. From Russia this formation extends across the whole of north Germany; dolomitic prolongations, the edge of the lens as it were, reach England. Everywhere it follows the Rothliegende, nowhere does it pass beyond, reaching at most the extreme outer border of that series; thus it is well known in Silesia, but not on the Bohemian mass.

The Zechstein marks a recurrence peculiar to central Europe and to a part of northern Europe. It does not penetrate into the Alps. On the other hand, it appears far away, in Kansas, represented by beds overlying the Fusulina limestone and containing a fauna comparable with that of the European Zechstein.

We have now reached one of the most remarkable phases of the earth's history; and, putting detail entirely aside, we will carry our survey beyond the confines of Europe and the United States, and endeavour to obtain a general view of the whole course of events.

Let us once more return to the base of the Carboniferous system, or the Calciferous limestone of Scotland, the equivalents of which we have already recognized on the other side of the Atlantic Ocean. The stratified series of Fife, with its still-rooted Stigmaria standing between the marine intercalations, affords clearer proof than any observations hitherto made of repeated oscillations with a positive excess, a phenomenon not to be

confounded with the alternation of paralic beds. In Illinois and the south-east of Russia the contemporaneous formations were purely marine. Perhaps the whole series of sandstone and coal beds which extends from Banks land over the north coast of Melville sound to Baffin bay must also be referred to the same origin.

The positive movement now conducts us to the most important pelagic member of the period, the Carboniferous limestone, which reveals, not only by its calcareous composition and its rich marine fauna, but above all by its mighty transgression, the far-reaching changes in the geography of the coast. It rests normally on the older Palaeozoic series from the far North to Brazil and Australia, but at the same time exceeds their limits. In Ireland, England, Scotland, and Spitzbergen it lies as a purely marine limestone on the Old Red sandstone, the only characteristic fossils of which are Ganoids and terrestrial plants; it extends at the same time through the Parry islands into the highest known latitudes. In central and southern Greenland it has not been observed. It proceeds through a large part of the great ranges of Asia, and in east China it rests on the Devonian and Silurian of the Tsin-ling-shan, overlaps them north of the Wei-Ho, and stretches along the sea from the north of Shensi to Shan-tung and Liao-tung, resting everywhere within this ancient table-land in apparent concordance upon the Cambrian beds. In like manner in the east part of the United States it rests on Devonian, extending to the west and south-west. In Dakota and the Rocky mountains of Colorado it follows in deceptive conformity upon Cambrian beds as in north China; at the bottom of the Grand Cañon a great plane of erosion separates it from the Cambrian or still older beds, but in the table-land of Texas, Cambrian rock reappears, immediately overlain, and again in apparent concordance, by the Carboniferous limestone. In California, so far as we know at present, the Carboniferous limestone is the sole representative of the entire Palaeozoic series.

This great transgression is succeeded, so far as we can judge from the facts, by a very marked and extensive negative phase. The flora of the lowest horizons of the resulting Coal-measures, i.e. the Culm flora, is known in the Arctic regions, in Europe, at many places in Siberia, and as far as Australia, where it is represented by several characteristic species. Thick masses of clastic sediments overlie the Carboniferous limestone in the United States, in the east of Canada, in central Europe, and in China; in central Europe the marine Gannister beds are intercalated with the lower Coal-measures, and after a remarkable sinking of the strand the signs of renewed ascent are revealed in the thickness of the sediments and the continuance of the limnic transgression.

This ascent finally led to a renewed appearance of the sea. It is the upper Carboniferous sea of the Fusulina limestone. The plant remains

determined by Stur—which lie in the shales between the beds of the Fusulina limestone on the Kronalp in Carinthia—leave no room for doubt as to the contemporaneity of this marine limestone with the higher Radowenz or upper Ottweiler Coal-measures, that is with the uppermost flora of the coal basin of lower Silesia and Bohemia. This new marine deposit, however, does not extend nearly so far to the north as the Carboniferous limestone. In Illinois it alternates with the Coal-measures, thins off towards Ohio and north Virginia, and does not reach Pennsylvania or Canada. In Europe it is found in north Spain; Meunier encountered it on the Morvan; in the southern Alps it alternates with plant-bearing beds; then it reappears in the south of Russia; Neumayr has recognized it in the north-west of Asia Minor; Teller in the island of Chios. Everywhere the sea appears to have come from the south. Similarly, all the specimens of Fusulina limestone so far described by Schwager from Richthofen's collections, and the rich upper Carboniferous fauna of Loping in the province of Kiang-si, lat. 27° 52′ N., studied by Kayser, belong to districts which lie south of the Tsin-ling-shan.

Now came the extension of the Rothliegende over Russia and central Europe, and even into some parts of the southern Alps; then, the positive movement still continuing, the Zechstein followed, extending from Russia through north Germany into England. It was a shallow sea; salt and gypsum crystallized out from it. During the period of this transgression, which came from the north, and perhaps also during the Rothliegende, a new fauna was introduced from the south, which has not yet received a particular name. It includes Carboniferous and Permian species and some new types, and is known to extend from the Salt range of India through the great ranges of Asia, Afghanistan, Djoulfa, in the valley of the Araxes, and past Artinsk in the Ural to Sicily. Its most northerly representative is perhaps the fauna of the Bellerophon beds in the south-eastern Alps; these beds, however, like the Zechstein, rest upon the Rothliegende [1].

While submergence and emergence thus alternate over regions of such vast extent, the outlines of a great continent become disclosed to us, and from the closing days of the Carboniferous this remains for a long period one of the most prominent features of the face of the earth. On a previous page (I, p. 387) it has been described as the fractured Indian continent, or *Gondwána land*. At the present day it is broken up by the Indian Ocean, and comprises the peninsula of India, Australia, and a large part of Africa.

[1] E. von Mojsisovics, Ueber das Vorkommen einer muthmasslich vortriadischen Cephalopoden-Fauna in Sicilien, Verh. k. k. geol. Reichs., 1882, p. 31; G. Stache, Zur Fauna der Bellorophonkalke Südtirols, Jahrb. k. k. geol. Reichs., 1877, XXVII, pp. 271–318; and 1878, XXVIII, pp. 93–168, pl.

The investigations of recent years, and the discoveries made by Warth in the Salt range, have helped to complete our knowledge of this continent. In the Salt range erratic blocks transported by ice occur at a horizon which, according to Waagen, must be correlated with the highest subdivisions of the Carboniferous system [1]. They are the same accumulations which constitute the Talchír conglomerate, or the lowest stage of the plant-bearing Gondwána series, in which Blanford, Oldham, and Fedden have recognized the influence of ice (I, p. 404); they also form, as the Dwyka or Ecca conglomerate, the foundations of the Karoo formation in Africa, and were long ago declared by Sutherland to be of glacial origin (I, p. 389).

The same glacial beds also make their appearance in east Australia, as the Bacchus marsh or Stony creek beds. There they alternate with marine beds which are referred to the Carboniferous.

They are immediately succeeded in India, Africa, and Australia by the long series of plant-bearing beds which ascend high into the Mesozoic group. For a long time the whole region remained above the sea. Then, during the Mesozoic aera, it gave way, breaking up piece by piece, the process probably continuing down to a comparatively late period, and large parts of it have not even yet been reached by the sea.

According to Waagen the glacial region extended from lat. 40° S. to lat. 35° N. and from long. 18° E. to long. 135° E. Some typical plants of the Culm flora are known in Australia, but the upper floras of the Carboniferous of Europe and North America have not been discovered on this continent. Over the whole of Gondwána land an independent series of floras makes its appearance under the influence of a severe climate.

In Europe erratic blocks of wholly enigmatical origin have been met with in the lower horizons of the Coal-measures, e. g. in proximity to a marine intercalation near Ostrau. According to Ramsay and Geikie signs of glacial action are to be met with in the Rothliegende of England.

Opinions as to what are the precise equivalents in Europe of the glacial conglomerates of India are not yet in absolute agreement. According to Waagen, as already mentioned, they should be placed on the horizon of the highest divisions of the Carboniferous; in Australia, glacial conditions would seem to recur in the Permian period.

The Carboniferous limestone of the far north contains a number of species also found in the Zechstein; its relations to the Zechstein do not appear to me to be as yet completely explained.

6. *Survey of the Palaeozoic seas.* The question whether the changes in the distribution of the seas can be explained by a secular rise and fall of the continents may receive some illumination from the history of the Palaeozoic seas.

[1] W. Waagen, Die carbone Eiszeit, tom. cit., 1887, pp. 143–192.

We have recognized the existence of two continents, of which fragments only are visible at the present day. The first occupied the position of the north Atlantic Ocean, as is indicated by the nature and distribution of the Palaeozoic sediments in Europe and America; Greenland is a remnant of it. This ancient continent is the *Atlantis*.

The second continent, first clearly discernible towards the close of the Carboniferous period, is now represented by three fragments, Africa, India and Australia. As Greenland on the one hand, so the Indian peninsula on the other projects into the Ocean which covers the subsided table-lands. This continent is *Gondwána land*.

The destruction of the two continents was accomplished later, piece by piece, and we can follow the process through many stages. It must have produced many negative movements and thereby have led to the abandonment of other regions by the sea. Further, our stratigraphical inquiries have so far advanced that it has become possible to recognize a number of positive and negative displacements which affected very extensive areas in a uniform manner.

At the close of the Silurian period the sea became shallower over a wide region, from Illinois and Iowa to Wisconsin and New York, in England, the Baltic provinces, and as far as the Dniestr. Then the Old Red sandstone advanced over a great part of the Atlantis. Evidence of its encroachment may be observed in Scotland, England, the gulf of Finland, and as far as the gulf of Onega and Spitzbergen, perhaps as far as the south of Greenland; and its equivalents, retaining the same characters, appear in New Brunswick. Towards the middle of the Devonian, the marine transgression extended over these continental or at most sublittoral deposits, and attained its maximum. The limestone and dolomite deposits of the middle Devonian extend over Orel and Voronezh to Livonia and Courland, and at the same time the transgressive middle Devonian appears to form the western glint of the Canadian shield from the Clear-water to the Arctic Ocean. In the oil-bearing beds on the shores of the Uchta, in the region of the Petchora, we recognize the oil-bearing shales of the banks of the Athabasca, which may be traced in North America from the valley of that river as far as the Gaspé. Then the shore again receded for a great distance, and the Carboniferous period began.

From the limnic or littoral formations, which in some localities seem to show signs of frequent secondary oscillations with a positive preponderance, we pass to the Carboniferous limestone. Simultaneously with the appearance of pelagic characters, the transgression is found to advance beyond the limits of earlier deposits; it occurs in regions the most remote from each other, as in China and Texas.

Once more the strand receded over a wide area, and then again advanced, evidently from the south, but it did not proceed nearly so far as during the

Carboniferous limestone period. This is the sea of the upper Carboniferous or Fusulina limestone.

Yet another marine fauna made its way from Asia across the Araxes, past Artinsk, to Sicily; whether or not it is represented in the south-eastern Alps is somewhat uncertain. It did not attain to the extension of the preceding stage. It is not known in the United States. Simultaneously with this fauna, the sea came down from the north and spread out the Zechstein over northern and central Europe.

Much no doubt still remains obscure. The Palaeozoic deposits of the Sahara, Brazil, and other very extensive regions, can hardly be taken into account in comparisons of this kind, and in the present state of our knowledge it is not possible to oppose in the Palaeozoic aera a compensatory negative region against a given positive region. Nevertheless we can already recognize three faunas which are foreign to the north of Europe, namely, the Hercynian stage, the Fusulina limestone, and the stage of Djoulfa. On the other hand the typical Zechstein is not known in the southern regions.

Positive and negative movements alternate simultaneously over regions of such vast extent, that they cannot be explained by a bulging or a sagging of the lithosphere on however great a scale. During the Carboniferous and at other periods also, considerable foldings of the lithosphere occurred, but they have nothing in common with this phenomenon of general inundation and emergence. The Armorican and Variscan folds arose in complete independence of the transgressions, by the progress of which these folds themselves were planed down and covered up.

CHAPTER VI

MESOZOIC SEAS

The seas of the Trias. Positive movements in the Rhaetic epoch. Continuation of positive movements during the Jurassic period. Negative phase in central Europe and commencement of the Cretaceous period. Later transgressions and intermixture of the Cretaceous faunas. The Cenomanian transgression. General survey of the Mesozoic seas.

1. *Seas of the Trias.* In the east of the United States the marine Mesozoic series is absent until we reach the middle Cretaceous. The Rhaetic and Lias lignites of the Appalachians clearly show that during their formation this region was not covered by the sea. Towards the west, however, first, marine upper Jurassic is met with in the Black mountains of Dakota, then the marine Trias makes its appearance in the western part of the Basin ranges, and last the Neocomian in California.

In Brazil likewise, marine sediments are completely absent from the beginning of the Mesozoic aera up to the middle of the Cretaceous. Even far to the west, in Jujuy and Salta, the northern provinces of the Argentine republic, we still meet with Rhaetic plant-bearing beds. Still further to the west, however, in the Andes of Chili and Peru, we encounter various marine members of the Trias, the Jurassic and the lower Cretaceous.

In eastern Australia there is a similar absence of marine sediments from the beginning of the Trias upwards, but the gap extends in this case only as far as the lower Cretaceous; the whole of this interval is represented by a few plant-bearing sediments only, such as the Jerusalem beds in Tasmania and the Clarence river beds in New South Wales and Queensland. In New Zealand, on the other hand, the marine Trias is present as well as marine members of the Jurassic. Here the series does not appear to be quite complete, and some plant-bearing sediments again alternate with marine beds.

In the north-east of China the marine series terminates in general with the Carboniferous; not even the marine deposits of the middle Cretaceous, elsewhere so widely distributed, have hitherto been encountered there. But the marine Trias, together with some members of the marine Jurassic, is known in the mountain-chains of Japan. In Yezo and Saghalin only the middle Cretaceous has so far been observed.

In the arc of the Aleutian islands, Trias, Jurassic, and Cretaceous are represented by marine deposits.

We may thus fairly conclude that in proportion as we approach the Pacific Ocean that important part of the Mesozoic series which is older than the middle Cretaceous becomes more complete.

The Atlantic border differs completely. With the exception of the two regions constructed on the Pacific type, the Antilles and the straits of Gibraltar, perhaps also the outrunners of the chains as far as the Wadi Draa and some parts of Europe, marine Mesozoic sediments older than the middle Cretaceous do not appear at all on the Atlantic coasts. This is the case from cape Horn to beyond the mouth of the Orinoco, from Florida to the Arctic Ocean and cape Farewell, and from the Wadi Draa to the cape of Good Hope.

The Indian Ocean presents both types. On the shores of Arakan, where the Pacific structure is the rule, the marine Trias is known to exist, but it is not found anywhere else along the coast of this Ocean. Thus here also a great gap occurs in the lower half of the Mesozoic series, but it does not extend as far as the middle Cretaceous, and indeed no further than the middle Jurassic.

From this it follows that the *existing Oceans are of different age.*

The distribution of *Pseudomonotis Ochotica*, one of the most characteristic species of the Trias, is of particular interest; discovered, as we have already mentioned, by Middendorf in Mamgá bay (sea of Okhotsk), it is recorded in Teller's tables as having been found subsequently at a great number of other localities; at several places in Japan, particularly in the bay of Sendai; on the island of Hugon; in New Caledonia; at several places in the Alps of New Zealand; as a closely allied variety, on the rio Utcubamba, between Chachapoyas and Cuelap, Peru; in Plumas county, California, Humboldt mountain, Nevada, and at several other places in these chains; near fort Rupert, Vancouver; in Moresby island, Queen Charlotte group; on the Peace river, on the east slope of the Rocky mountains (lat. 50° to 57° N.); at cape Nunakalkhak, at the entrance to the bay of Povaluk, Alaska; finally near Verkhojansk on the Jama in east Siberia (lat. 63° N.)[1].

Thus the marine Trias engirdles the Pacific Ocean; it is continued across Siberia from the mouth of the Olenek to Spitzbergen, but it does not reach the Atlantic region by this route.

Mention has been made (I, p. 581) of the marine Trias of Arakan. Its thick series of sediments help to form the great ranges of Asia, but their connexion with the Trias of the Alps is still little known. Griesbach's widely extended investigations in Afghan Turkestan show that *Halobia Lommeli* of the upper Alpine Trias recurs near Chahil, north-west

[1] F. Teller, Die Pelecypoden-Fauna von Werchojansk in Ost-Sibirien, in E. Mojsisovics von Mojsvár, Arktische Triasfaunen; Mém. Acad. Imp. Sci. Saint-Pétersb., 1886, XXXIII, No. 6, p. 103 et seq.

of Saighan in Turkestan[1]. But it appears there associated with plant-bearing beds, which represent part of the Gondwána series of India, and we have seen that a lower part of this series enters into the structure of the great ranges near Darjiling (I, p. 577).

Further to the west information is wanting. In Russian Turkestan the Trias is absent. In the Caucasus only plant-bearing beds are known below the Lias, to which they are supposed still to belong. Mojsisovics, who has rendered such great service in determining the subdivision of the Trias, believes he has found indications of the lower Alpine Trias above the Permo-Carboniferous sediments of Djoulfa in Armenia; but it was the collections sent by Russian geologists from the mountain of Bogdo on the lower Volga, which first enabled him to prove definitely the presence of the Alpine Trias in this region. In the north-west of Asia Minor, on the lower Danube, in the Balkans, in the Carpathians, and in the Mittelgebirge of Hungary, this formation appears with increasing frequency until we reach the region of the eastern Alps. From here the sediments of this group extend to the Grisons, the southern Alps and Bosnia, and proceed through the Apennines to Sicily; they are found, though not with the same characters, in the northern slopes of the Swiss Alps and cross the Balearic isles to the Ebro.

These facts reveal to us a sea which extended from the interior of Asia over the south of Europe. It is this sea which the study of the distribution of the Jurassic sediments disclosed to Neumayr, and it has been named by him the '*Central Mediterranean*[2].'

We have seen from three examples, namely from the Hercynian stage of the lower Devonian, from the Fusulina limestone of the upper Carboniferous, and from the Permo-Carboniferous deposits of Djoulfa, that calcareous marine formations occur in the south and south-east of Europe; while clastic sediments and the deposits formed in shallow water prevail towards the middle or the north-west. The same phenomenon presents itself again in the Trias. Even in the regions where the system first received this name (central and northern Germany, together with England and a large part of France, including the Jura and the Département du Var), it presents itself with a local and abnormal facies: clastic and sublittoral, lacustrine, and saliferous deposits assume far greater prominence here than elsewhere, and its development in these regions as the triad group, Bunter sandstone, Muschelkalk, and Keuper, affords a striking example of a sedimentary cycle, with a lenticular mass of limestone as the middle term. The Muschelkalk indeed is absent towards the north-

[1] C. L. Griesbach, Field Notes: No. 5, to accompany a Geological Sketch-map of Afghanistán and North-eastern Khorassan; Rec. Geol. Surv. India, 1887, XX, p. 97 et seq.

[2] M. Neumayr, Die geographische Verbreitung der Juraformation; Denkschr. k. Akad. Wiss. Wien, 1885, L, pp. 57–86, maps.

west, namely in the western part of the basin of Paris, and in England; there the Keuper rests directly upon the Bunter sandstone, often only with difficulty to be distinguished from it.

It was impossible to arrive at a correct interpretation of the most important of these regions, so long as the horsts of the Rhine, the Black Forest, and the Vosges were regarded as parts of an ancient coast. Benecke, as early as 1877, had liberated himself from this mistaken theory, and was then led to formulate general views in respect to the west of central Europe[1]. But if we follow in detail the descriptions of Benecke, Sandberger, and other German investigators, we perceive the danger of a too simplified and too generalized conception of the Trias as representing a regular cycle. The Bunter sandstone is indeed a transgressive deposit marking a positive period; it rests on rocks of very different age. But the beds of various nature which are intercalated in this series, sometimes containing marine shells, at others terrestrial plants, and composed in some cases of dolomitic limestone; or again, the variegated gypsiferous clays of the middle Muschelkalk, the various salt-bearing zones, and the repeated interbedding of dolomite with the Keuper, which includes here and there, as far as north Germany, isolated marine mollusca, and near Würzburg even *Myophoria Raibliana*, so widely distributed in the eastern Alps—all these are only a few of the many anomalies, probably true recurrences, which interrupt the cycle. At the same time, with the progress of events, the sediments continued to increase in thickness, until finally, at the close of the Keuper, the littoral sediments of the Rhaetic, which forms the next stage, extended beyond the limits of the Trias on to the older rocks, indicating a higher level of the coast-line than had at any time existed during that period.

The calcareous deposits of the extra-Alpine Trias are always, wherever they occur, intercalated between the two clastic members, the Bunter sandstone and the Keuper. Their distribution corresponds in a striking manner with that of the Zechstein, but is not so extensive. Here we have a cycle accomplished in oscillations.

Contemporaneously, sediments of quite a different nature were deposited in the eastern Alps. They are almost exclusively of pelagic origin and distinguished by a rich fauna; limestone and dolomite attain a considerable thickness in this region.

A very singular development characterizes the Trias in south Tyrol.

F. von Richthofen observed that at certain horizons of the Trias in this region vast masses of limestone and dolomite protrude, forming mountains with steep slopes, and that between these masses and on their flanks clastic sediments and volcanic tuffs have been deposited. He regarded them as

[1] E. W. Benecke, Ueber die Trias in Elsass-Lothringen und Luxemburg; Abh. z. geol. Specialkarte v. Elsass-Lothringen, 1877, I, Heft 4.

coral reefs. Gümbel raised the objection that corals are rare in these limestones, and that for the most part they are stratified. The facts of the case are clearly set forth in the descriptions given by E. von Mojsisovics and his fellow workers, H. Hoernes and C. Doelter[1]. Mountainous masses of limestone and dolomite are buried up in the clastic sediments of the Trias. The form of these masses does not correspond with that of the mountains, except in those rare cases where the outer slopes of the reef have been exposed by denudation, and persist as the existing slopes of the mountain. Most of the masses are stratified, but some not. Mojsisovics thinks the unstratified masses are coral reefs. On the outer slope of such masses ancient accumulations of débris with 'overcast-bedding' are sometimes to be seen. That the expression 'reef' is justified can hardly be doubted. In the lower horizons we may observe between the Adige and the valley of the Sexten two regions of reefs, a western and an eastern; in the intervening district the reefs are wholly missing. At a later period, when the Saint Cassian beds had been deposited, these two regions of reefs were united in a band which runs through Caprile, Pieve di Cadore, and Auronzo, so that the area of deposition of the clastic sediments was diminished. We may add that at a still higher horizon of the Plattenkalk the stratified beds extended over the whole region.

In the northern Alps massive or stratified limestones and dolomites have been found in more or less continuous sheets. We will restrict our attention to the upper beds, which are so intimately associated with the Rhaetic stage.

2. *Positive movements in the Rhaetic period.* Standing near the Königssee near Berchtesgaden, we may readily distinguish in the white wall of cliffs above Sankt Bartholomae two well-marked subdivisions: the rock below is grey, unstratified, splintery, and weathers into numerous sharp cones; that above is divided by regular bedding-planes and crowns all the higher summits of the cliffs. But if, south of the lake, we ascend the height of the Steinernes Meer, the eye sweeps over a panorama of mountains which, as far up as the peak of the Watzmann, are traversed by the same regular bedding-planes. This member of the Alpine limestone immediately underlying the Rhaetic stage has received the characteristic name of *Plattenkalk*. It has been traced from the Vorarlberg to the eastern extremity of the Alps near Vienna, as well as through the whole limestone region of the southern Alps, and, maintaining the same characters, in the faulted-in band of the limestone which traverses Carinthia. We may also include with it the stratified limestone masses of the *Dachstein*

[1] F. von Richthofen, Geognostische Beschreibung von Predazzo, St. Cassian und der Seisser-Alpe, 4to, Gotha, 1860; C. W. Gümbel, Das Mendel- und Schlerngebirge, Sitzber. k. bayr. Akad., 1873, p. 71 et seq.; E. Mojsisovics von Mojsvár, Die Dolomitriffe von Süd-Tyrol und Venetien, 8vo, Wien, 1879.

mountains, and regard Plattenkalk and Dachsteinkalk as synonymous terms. The pale limestones, however, which overlie the richly fossiliferous beds of the Rhaetic stage, and in the western part of the northern Alps are usually spoken of as Dachsteinkalk or upper Dachsteinkalk in opposition to Plattenkalk, are only a recurrence of the beds of the Plattenkalk at a higher stage.

That the shells of foraminifera form a large part of the substance of these limestones was known long ago to Schafhäutl and Gümbel; in 1863, Peters showed by an examination of thin slices that the limestone of the Dachstein mountains and the Terglou abounds in micro-organisms[1]. But they present many other instructive characters; a wide and attractive field of investigation opens out here, as yet hardly touched, and I can therefore only offer a few preliminary observations.

FIG. 27. *View from the Oberlahner, ascent to the Funtensee Alp, Steinernes Meer.*

Let us approach more closely one of the colossal limestone walls. We may first call attention to the bright red shards which are strewn through some of the beds. Sometimes these fragments are angular, and look as though they had been broken off from a hard red bed; sometimes they are thinly laminated in red and yellow layers; sometimes, again, we see lying in the limestone one of the great shells of Megalodus filled with red material up to a level line, above this either white limestone or calcspar. This red material is the *terra rossa* of the Karst and of the emerged coral reefs of Oceania, the residue left after the solution of limestone, and thus scarcely likely to have been formed beneath the sea.

Next the behaviour of the *corals* must be considered. In the light grey limestone, branches of great coral growths replaced by white calcspar are visible, which owing to the difficulty of a closer determination are generally described as Lithodendron. The radiating branches present a rosette-like or nodular form; sometimes, indeed, rosettes of this kind are

[1] K. F. Peters, Ueber Foraminiferen im Dachsteinkalk; Jahrb. k. k. geol. Reichs., 1863, XIII, pp. 293-298.

seen seated on the shell of a great Megalodus. But the Lithodendron corals are not only scattered through the limestone. There are some beds which are entirely made up of them; their branches are more or less vertical, the intervals between them being filled up with limestone. These are true coral limestones. At the base these beds are separated by a bedding-plane from the underlying limestone, but strange to say they are similarly separated above from the next succeeding bed by a continuous plane of division which may frequently be followed for a great distance along the face of the cliff: their knoll-like masses and branches do not extend into the next limestone bed, contrary to what, from the irregularity of their growth, we might naturally have expected. I even remember to have seen, several years ago, in the cliffs of the Schladminger loch in the Dachstein mountains, two coral beds of this kind, separated by a trifling interval, maintaining for an indefinite distance a constant thickness. Whether the upper surface is a plane of erosion such as is produced by the sea on the borders of existing coral reefs, I am unable to say.

The beds themselves vary greatly in character. Sometimes they are grey, very splintery, and without a trace of organic remains, at others pale yellowish or greyish white, breaking with an even fracture, and occasionally rich in fossils. These beds of different nature occur in repeated alternations.

They often contain over 40 per cent. of magnesium carbonate: there can be no doubt that in these cases dolomite has been precipitated as such from the sea[1].

Beneath are beds which contain numerous minute organisms, and outwardly bear no resemblance to a dolomite.

The internal structure of the beds is also very various. Some are laminated, as is clearly shown by the weathered surfaces, even in the case of the Gyroporella beds of the Rax Alp in lower Austria which belong to a lower horizon. Others contain larger or smaller fragments of limestone of a different origin, which are often only revealed by polishing. In the Dachstein mountains, on the left side of the Karls-Eisfeld, beneath the Schoberl, *Rhynchonella ancilla* is found in immense numbers. Freshly broken out blocks of the rock show, however, when polished, that the Rhynchonellas are embedded in fragments of a light grey limestone, which are derivative, forming foreign inclusions in this bed. The polished surfaces also reveal fragments of a yellowish-white limestone, containing other organic remains, and of an unfossiliferous grey limestone, as well

[1] Gümbel has always maintained this view; the dolomitic intercalations in the Potsdam Sandstone, the Waterlime of the upper Silurian of North America, the dolomitic beds of the upper Devonian of Russia, those which represent the Zechstein in England and those in the German Keuper, all of them more or less littoral deposits, are so many examples of the direct deposition of dolomite.

as parts which are coloured by red earth in bands of lighter and darker tints.

A further peculiarity is the *incrustation* of the included fragments. It not seldom happens, and an excellent instance is afforded by the Karls-Eisfeld rock, that each of these derivative components has been covered with a thick crust of carbonate of lime, which was deposited before the formation of the matrix. In sections this crust shows a radiate structure. Occasionally adjacent fragments are enclosed in a common crust. This case differs completely from that in which carbonate of lime fills up the interior of shells, as for instance the brachiopods of the Vils beds, and replacing the rock forms in some cases the whole of the matrix as well, as has been described by Rothpletz[1]; it is the incrustation of the fragments by sinter, followed by their cementation together, before the formation of the matrix and the completion of the rock. It is not easy to understand how this process could take place beneath the sea.

We have next to consider the *mode of separation of the beds.* In some series successive beds are separated by sharply marked divisional planes, but are not distinguished by any lithological differences; in other cases a bed may consist of two or three layers clearly defined from each other by differences of colour and texture, but yet not separated by any interruption of continuity[2].

It not seldom happens that a single bed consists of two or even three layers, which are not separated by bedding planes but by a dark, acutely denticulate line, not unlike a cranial suture. They have been described by Gümbel and Pichler; Rothpletz describes them under the name of 'Sutures.' They have not been formed by pressure, as has been supposed; if, taking advantage of the thin film of clay which is seen in section as the dark jagged line of demarcation, we succeed in exposing the surface of separation, we perceive that it is a true stylolith formation, i.e. that numerous particles of the upper deposit have sunk into the lower, forming a number of cones[3].

[1] A. Rothpletz, Geologisch-paläontologische Monographie der Vilser-Alpen; Paläontographica, XXXIII, p. 66, pl. xv, fig. 17. Bischof has shown what weighty grounds there are for the belief that carbonate of lime is not precipitated in the sea without the assistance of organisms; Loretz has observed foraminiferae in thin slices, surrounded in like manner by zones of radiate structure; Zeitschr. deutsch. geol. Ges., 1878, XXX, p. 412, pl. xviii, fig. 11.

[2] E. Suess und E. von Mojsisovics, Studien über die Gliederung der Trias- und Jurabildungen in den östlichen Alpen; II, Die Gebirgsgruppe des Osterhornes, Jahrb. k. k. geol. Reichs., 1868, XVIII, pp. 167-200.

[3] These sutures may be seen in the polished faces of blocks of upper Jurassic and lower Cretaceous limestone used in the buildings of upper Italy, but here, so far as I have observed them, they only separate beds of the same nature. A bed is seen on the Osterhorn (No. 22 in the list in Jahrb. k. k. geol. Reichs., 1868, p. 172) which consists, at its base, of a reddish brown; above, of a grey layer. The lower layer (*a*) contains many organic remains, including corals, and the upper grey layer (*b*) penetrates from above

We now come to the last and most important of these structures, the *partings*. The bedding-planes are usually characterized by the presence of an argillaceous matter, foreign to the rock. The localities where these intercalations or partings occur are, however, somewhat difficult to reach, and I cannot positively affirm that they are always present. On the Osterhorn, south of the Wolfgang-See, thin streaks of lustrous coal formed of drifted stems of plants make a rare appearance here and there in the uppermost beds of the Plattenkalk, not far below the lowest beds of the Rhaetic series. The partings are formed of black bituminous shale, containing remains of Ganoids, and numerous scale-like leaves and twigs of *Araucarites alpinus*. Notwithstanding the occasional layers of coal distributed through it, the limestone with its pale colour, its Megalodons and corals, presents a most striking contrast to the black shales with their fishes and terrestrial plants. These intercalations are continued towards the west. Von Ammon has described them in detail from the neighbourhood of Partenkirchen in Bavaria[1]. At Seefeld in Tyrol petroleum has long been obtained from these fish-bearing partings, and the drops of 'Saint Hubert's oil' which are sometimes seen floating on the water of the springs come from these beds. On the Osterhorn these partings are repeated several times in succession in the pale limestone; a little higher and then between the beds of this limestone we perceive the first calcareous shales containing bivalves, such as in Swabia characterize the littoral development of the Rhaetic series.

These beds themselves have at first more or less the character of partings; they increase in thickness, but the pale limestone continues to alternate with them in isolated bands; the whole series grows darker in colour, the clastic elements increase in importance; step by step as we ascend in the series, the mollusca of the deeper water preponderate more and more over those of the coast, until at length we find ourselves in the midst of the pelagic development of the Rhaetic series, yet once again the white limestone with Lithodendron makes its appearance in two beds, together 60 feet thick, and then finally the dark layers of the Rhaetic.

fairly deep into the cylindrical cavities of these corals. An analysis kindly made by Dr. C. Natterer shows:

	(*a*)	(*b*)
Water	0·04	0·05
Insoluble in hydrochloric acid	0·26	1·64
Iron, traces of phosphoric acid	0·13	0·30
$CaCO_3$	55·76	55·10
$MgCO_3$	44·13	42·76
	100·32	99·85

The two beds, so different in appearance, are therefore both true dolomites and differ only in the quantity of clay and iron they contain.

[1] L. von Ammon, Die Gastropoden des Hauptdolomites und des Plattenkalkes der Alpen; Abh. zool.-min. Ver. Regensburg, 1878, XI, pp. 46–55.

Thus we start with the result *that the first Rhaetic intercalations in the white limestones and dolomites are not deposits of the deep sea; they are characterized on the contrary by a littoral fauna.*

Another example of the succession, quite as striking as that of the Osterhorn, has been described by Zugmayr in lower Austria[1].

Close to the mill at Waldegg in the Piestingthal, where the thickness of the Plattenkalk is estimated as at least 1,000 meters, reddish marl appears as partings in the beds near the summit; these fill up the trifling depressions in the upper surface of the beds, and sometimes unite together to form thin continuous layers. They contain numerous scales, teeth of Gyrolepis, Sargodon, Saurichthys, Acrodus, and other fishes, and represent the bone bed which accompanies the Rhaetic series in its littoral development. They are repeated four or five times at least between the hard limestone beds. Next follows hard limestone, again with Megalodus, then a parting nearly two feet thick, with Rhaetic mollusca of a littoral character; again limestone, and another reddish layer with a bone bed, and then, after some closing alternations, the representatives of the rising Rhaetic sea, increasing continually in depth. It would be superfluous to multiply examples. The presence of the marls and red shards, the heaping together of the various kinds of limestone fragments, and perhaps also the encrusting sinter, all combine to show that the surface of some of the beds of the Plattenkalk was uncovered by the sea, exposed for a while to the air, and then again submerged. With the appearance of the Rhaetic shells we observe an increasing proportion of detrital sediments.

In the succession of the Osterhorn several facies may be distinguished, which represent so many different bathymetric stages in the Rhaetic sea. The first of these is the Swabian facies: a bone bed, layers with Mytilus and Taeniodon, with *Avicula contorta*, but without brachiopods. It is succeeded by the Carpathian facies with *Avicula contorta*, *Terebratula gregaria*, *Ostrea Haidingeri*. Then comes the Kössen facies with numerous brachiopods, such as *Spirigera oxycolpos*; and last of all the Salzburg facies with *Choristoceras Marshi* and *Avicula speciosa*.

The first three members of this series are found also at several localities in the north-eastern Alps. Schlönbach has described them at Kössen; they occur on the slopes of the Scesa plana in the Vorarlberg, as is shown by collections which Escher made in his time and presented to me, while in other parts of Vorarlberg the Carpathian facies seems to close the series. Stoppani has traced these deposits with great care along the whole of the limestone zone of the Italian Alps, and has divided them into two groups—a lower, consisting of shales and shelly limestones, the facies of which is

[1] H. Zugmayer, Ueber bonebedartige Vorkommnisse im Dachsteinkalke des Piestingthales; Jahrb. k. k. geol. Reichs., 1875, XXV, pp. 79–88.

purely Swabian; and an upper, the beds of Azzarola, the facies of which is as distinctly Carpathian [1].

The Swabian facies, maintaining a distinctly littoral character, extends far beyond the region of the Alps. At the most remote locality in Europe, Linksfield in Sutherland, it is only known in scattered blocks. From Scotland it extends into the north-east of Ireland, and is continued thence across the counties of Nottingham, Warwick, Worcester, Gloucester, and Somerset, to Dorset. Some obscure littoral patches occur on the coast of Scania; it is found over a large part of France, and the whole of central Germany. The Carpathian facies is far more restricted in its distribution. It scarcely extends beyond the region of the great folded mountains, but is known in the Jura, throughout the whole course of the Alps and the Carpathians, in the Apennines and in Corsica. It presents itself in typical development at Meillerie on the lake of Geneva (Favre), near the fall of Nünenen on the Stockhorn (Brunner), and south of Hindelang between the Iller and the Lech (Escher and Merian). The region of the Kössen facies is still more restricted. It is found in the north-east Alps, at several places in the Carpathians, and extends as far as Bukowina [2]. Sometimes the brachiopods of this zone lie together in dense masses in the light-red limestone of the Starhemberg beds, which occur only in the north-east Alps, as is the case also with the Salzburg facies, which has been less studied.

Thus in the Rhaetic series of the Alps, the littoral beds occupy the lowest position, beneath all the other subdivisions; at the same time they attain their greatest distribution over Europe.

The upper beds of the Plattenkalk in the Osterhorn were deposited during a series of oscillations with a preponderant positive movement. The preponderance, however, was so slight that the limestone was uncovered by the sea after its deposition. It remained exposed to the air during the whole of the negative recurrence and the corresponding part of the next positive phase (*−ef* to *+kl*, II, p. 25). As the periods of submergence became more and more prolonged, terrigenous sediment made its appearance, consisting, however, not of sand, but of clay, and with it a littoral molluscan fauna. With the persistence of the positive movement the Swabian facies was replaced first by the Carpathian, and then by the Kössen facies, so rich in brachiopods. At the same time the whole of the central European sea advanced further and further beyond its previous bounds. While, in the Alps, beds with the Kössen facies accumulated in

[1] U. Schlönbach, Verh. k. k. geol. Reichs., 1867, p. 211; A. Stoppani, Essai sur les conditions générales des couches à *Avicula contorta* et sur la constitution géologique et paléontologique spéciale de ces mêmes couches en Lombardie, 4to, Milano, 1861, and supplement, 1863. Lepsius has described a Cyrena of the Swabian facies from the south Alps which points to fresh or brackish water; cf. his Das westliche Süd-Tyrol, 4to, Berlin, 1878, p. 360; the stratified succession, op. cit., p. 102.

[2] Its occurrence near Taormina in Sicily has been recently disputed.

deep water over the now completely buried Plattenkalk, elsewhere, as on the distant shores of England and Scotland, littoral beds were deposited. These continually advanced inland, characterized by the same bone bed and the same fossils as are to be found in the eastern Alps, where they occur either in the partings of the light-coloured Plattenkalk, or in the beds immediately above this stage.

If we ascend the foot of the Osterhorn to about 200 meters above the first intercalation of the Swabian facies, we shall still find ourselves among comparatively deep-sea deposits, here represented by the layers rich in brachiopods. The positive excess of the oscillations must consequently have amounted to more than 200 meters, otherwise none but littoral beds would have been deposited on the site of the Osterhorn. Hence (Pos. $+\alpha$ $+\sigma-$Neg.) >200 meters (II, p. 220). This positive movement manifests itself in the littoral regions by a transgression which has been traced by Hébert and Martin over the whole of the south of the Central Plateau of France, from the valley of the Rhone through the departments of Ardèche, Gard, Lozère, Corrèze, and Dordogne, as well as over the north in the Nièvre, Côte-d'Or, and Saône-et-Loire. This led Hébert to conclude that the Central Plateau had undergone a gradual subsidence in the Rhaetic period [1]. In England, also, signs of this transgression are not wanting, and it may have left its mark in still more distant localities.

Thus, on the lake of Geneva we find, according to Favre, the Carpathian facies lying at a higher level than the Swabian [2]; in like manner in England, the Rhaetic stage, where it is best known, as in Somersetshire and on the borders of the Severn, as well as further north in Nottinghamshire, consists of sandstone with one or more layers of bone bed, and it is not till we pass a little above this that shales, thin seams of limestone, and the mollusca of Swabian facies make their appearance [3].

Our study of the numerous observations made on the stratified succes-

[1] E. Hébert, Les Mers anciennes et leurs rivages dans le bassin de Paris, 8vo, 1857; J. Martin, Zone à *Avicula contorta* ou Étage Rhétien, 8vo, Paris, 1865, in particular p. 175.

[2] A. Favre, Mémoire sur les terrains liasique et keupérien de la Savoie; Mém. Soc. phys. et hist. nat. Genève, 1859, XV, a, pp. 112 and 181.

[3] T. Wright, Monograph of the Lias Ammonites, Palae. Soc., 1878, p. 5 et seq.; E. Wilson, The Rhaetics of Nottinghamshire, Quart. Journ. Geol. Soc., 1882, XXXVII, pp. 451-456. As early as 1860 Mr. C. Moore, of Ilminster, was good enough to send me all the Rhaetic specimens of his collection, and Mr. T. Davidson, of Brighton, and Mr. T. Wright, of Cheltenham, have kindly furnished me with much information on this subject. A journey to England completed my acquaintance with the deposits of that country. My object was to obtain a general idea of the Rhaetic sea. A deeper knowledge of the facts served to enlarge the task; my kind friends, Davidson, Moore and Wright, as well as Escher and Oppel, are long since dead, and it is only now that I am at last able to give here my final results. *Discina Cellensis* from the Bürger-Alpe, Mariazell, and *Discina Townshendi*, Forbes, from Frome near Bristol, are identical. Oppel also sent me specimens of this species from Reit im Winkel.

sion and distribution of the Rhaetic series has now advanced so far as to enable us to form some idea of the processes which accompanied the apparition of this new marine fauna, and to recognize and distinguish the signs of positive movement, on the one hand in the middle of the sea basins, and on the other in the littoral regions. At the same time we perceive that the dominant positive movement was not local, but extended as far as it is possible to pursue our investigations. Neither was it a sudden event, but oscillatory and slow.

The presence of the red shards, which reveal the influence of the atmosphere, and the partings with fish and terrestrial plants have not, however, hitherto been observed except in the Plattenkalk. We do not possess such evidence for all the beds, some hundreds in number, of which it is built up. It is possible that each bed corresponds to an emergence followed by a marine recurrence, but this is by no means certain. Indeed certain important facts are opposed to such a supposition; as for instance the observations already made on the splitting of coal seams (II, p. 245). The Carboniferous limestone beds are obviously formations of a similar kind to those of the Rhaetic epoch. The Fusulina of the upper Carboniferous limestone of the southern Alps have been drifted together into beds, in precisely the same way as the Gyroporella of the Rax-Alp. The paralic seams which occur between the beds of Fusulina limestone in the United States occupy the position of partings, and it is asserted of them that they unite together as they proceed landwards into larger, continuous, and probably autochthonous beds. Observations of this kind point far more to a periodic increase in the transport of sediment, than to extensive displacements of the strand-line. The tranquil deposition of the Gannister series, the marine beds of no great thickness or extent in which the gaping bivalve shells have sometimes been found (II, p. 240), indicate on the contrary, as it seems to me, a transitory positive phase.

Thus we are confronted by many an unsolved problem, and may almost envy our successors the discoveries which are reserved for them.

The importance of a careful study of the partings has at all events been rendered clear. Walcott sees in the Galena limestone of Illinois and Wisconsin the representative of the Utica slates, which were deposited in the east and north of the Silurian region of the United States; the transition is accomplished by the multiplication of the shaly partings in the limestone[1]. The Devonian limestone Gg_1 of Prague is divided into numerous regular beds by clayey partings, and Klvaña regards the superimposed Tentaculite shales Gg_2 as merely the continuation of the partings of Gg_1[2].

[1] C. D. Walcott, The Utica Slates and related Formations; Trans. Albany Instit., 1879, X, 38 pp., pl.

[2] J. Klvaña, Ueber die Silur-Schichten der beiden Moldau-Ufer, südlich von Prag; Verh. k. k. geol. Reichs., 1883, pp. 37–43. F. Katzer has subsequently examined these

It thus becomes easy to understand why Drasche, in view of the prevailing theories on coral reefs, was astonished to find the coralliferous limestone of Luzon, which extends up to considerable heights, divided into regular beds, and it is not to be wondered at that he should even put the question whether this apparent stratification, which also occurs in reefs rising but a few feet out of the sea, might not result from a periodic intermittence of the coral growth [1].

The Megalodus limestone and the Rhaetic series are not known outside the European area, except in the Himálaya and the outer chains of the Hindu Kush, in particular at mount Sirban, near Abbotabad. In addition, an isolated Rhaetic fossil was found among the specimens brought home by Payer from east Greenland. With the exception of the last-named locality the marine beds of the Rhaetic did not extend beyond that region which we will term, with Neumayr, the Central Mediterranean, or beyond that extension of it towards the south-west of Europe, which had already come into existence as early as the Trias.

Plant-bearing beds of Rhaetic age, on the other hand, are known in many places; e. g. in Siberia, Turkestan, Tongking, Australia, in the Gondwána and Karoo series, in the Argentine Republic, and in the eastern part of the United States.

In the coast region of the Pacific, again, no marine Rhaetic deposits so far as I am aware have yet been observed.

Indeed we have no knowledge at present of the occurrence anywhere of a rich marine fauna of this period. The Rhaetic beds with which we are acquainted contain a fauna of a somewhat restricted character. All those various groups of cephalopods which occur in the Trias and reappear in the Lias should also be found in the Rhaetic, but strange to say they are not, and we know not where to search for them. When, at last, in the uppermost part of the series a cephalopod does make its appearance, it is the singular genus Choristiceras.

3. *Progress of the positive movement in the Jurassic period.* We have ascended step by step from the beds of the Plattenkalk through the Rhaetic oscillations, until we have reached a state of things in which open sea occupied the place of the eastern Alps, and the strand was gradually moving outwards till it reached Scania and the north-east of Scotland.

Now, we propose to follow the further oscillations of the Lias and the later stages of the Jurassic system. Neumayr, bringing to his assistance all the recorded observations at his disposal, has attempted to follow over

rocks, and owing to the absence of Tentaculites in these intermediate beds has not confirmed this opinion, but the results coincide as regards the fact that the clay appears in repeated interruptions; F. Katzer, Ueber schieferige Einlagen in den Kalken der Barrande'schen Etage Gg_1, Sitzber. k. böhm. Ges. Wiss., 1886, pp. 466-472.

[1] R. von Drasche, Luzon, pp. 39 and 43. The same occurs on Cebú; Abella, Isla de Cebú, p. 127.

the whole face of the earth the geographical changes which marked this period. The unexpected result of this laborious investigation was to show that to the Lias a very limited distribution appertains, while the approaching close of the middle Jurassic is marked by a transgression of surpassing interest and extent [1].

It is clear, to begin with, that the oscillations persisted into the Lias. Here the two regions in proximity to the ancient coast, i. e. Scotland and Scania, again furnish important evidence.

In England, the further we advance towards the north, the more frequent become the intercalations of detrital and plant-bearing sediment in the Lias and other members of the Jurassic system, and they attain their greatest development in the isolated fragments which are preserved in Scotland, partly by faulting down, and partly by protection beneath basaltic sheets. Rightly to interpret these downthrown remnants, we must here, as in the Rhine valley, first admit that these now isolated patches are the remains of a once continuous mantle, which extended high over the whole of Scotland and its ancient horsts. Judd had already adopted this view, as early as 1873, and was thus led by the same path as Benecke in his study of Alsace, to a correct interpretation of the facts [2].

In the west of Scotland, as in the isle of Skye, for example, the Lias is still complete, but the argillaceous partings of the limestone beds have become much thicker. To the north-east, in Sutherland, it is so no longer; detrital, plant-bearing beds have taken the place of the lower subdivisions; and only the upper part of the lower Lias and the base of the middle Lias are represented by marine beds. It would seem, therefore, that it is these two latter horizons which attained the widest distribution in Europe.

The case is the same in Scania; littoral beds of Rhaetic age are followed by a series containing shells, which is only slightly littoral in character, and these are the sole representatives of the basal part of the Lias: the purely marine beds make their appearance on the same horizon as in Sutherland [3].

[1] M. Neumayr, Die geographische Verbreitung der Juraformation; Denkschr. k. Akad. Wiss. Wien, 1885, L, pp. 57–142, maps.

[2] J. W. Judd, The Secondary Rocks of Scotland, Quart. Journ. Geol. Soc., 1873, XXIX, pp. 97–197, and 1878, XXXIV, pp. 660–741, maps; for the west, also J. Bryce, On the Jurassic Rocks of Skye and Raasay, op. cit., 1873, XXIX, pp. 317–351.

[3] B. Lundgren, Undersökningar öfver Molluskfaunan i Sveriges äldre Mesozoiska Bildningar; Lunds Univ. Arsskrift, XVII, 4to, Lund, 1881. The same horizons which have the widest extension in Scotland and Scania also seem to be encountered in the Alps as the material filling fissures in the Plattenkalk. *Oxynoticeras oxynotus* is of frequent occurrence in north Scotland; cf. Geyer, Ueber die liasischen Cephalopoden des Hierlatz bei Hallstatt, Abh. k. k. geol. Reichs., XII, No. 4, 1886, p. 213 et seq.; by the same, Ueber die Lagerungsverhältnisse der Hierlatzschichten, Jahrb. k. k. geol. Reichs., XXXVI, 1886, pp. 216–294; F. Wähner, Zur heteropischen Differenzirung des alpinen Lias, tom. cit., passim. The fissures described by Wright in the south-east of England are of different age, as are the Tertiary fissures *m*, *m*, Fig. 34, I, p. 257.

We now enter the middle Jurassic. In Franconia and Swabia, the marine sediments follow one another, bed after bed, in undisturbed succession. This region was not subjected to negative recurrences. Indications of these are more evident in the north of France. Hébert commenced to trace them out in detail as early as 1857, and he then recognized that the Lias on the Sarthe is incomplete, and that at various horizons in the Jurassic hard beds present themselves with a water-worn, and indeed polished, surface perforated by boring shells, and he came to the conclusion that the Jurassic sea had enlarged its bounds by oscillatory movements up to the epoch of the Kelloway stage [1]. In Normandy, which I visited in 1856 under the friendly guidance of MM. Deslongchamps, the facts have been very exactly described by Eugène Deslongchamps. The Lias is incomplete, and its lower zones, speaking generally, appear to have been deposited in the north of the country only. Within the middle Jurassic, however, we may observe at various levels beds with a worn and perforated surface, known in the locality as 'chiens,' which indicate a temporary withdrawal of the sea. As early as 1864 Eugène Deslongchamps was led to conclude that during the Lias the sea in this region gradually extended its limits, and then, as the period approached its close, withdrew to a great distance; after this shallow water supervened, then another regression (*Trigonia navis*), followed by a fresh extension (*Harpoceras Murchisonae*). Above the beds of the inferior Oolite a worn surface, drilled by Lithodomus, makes its appearance, and with this a new positive movement is indicated, which continued, advancing by slow degrees, up to the great Callovian submergence (*Stephanoceras macrocephalum*) [2].

The Jurassic deposits are continued across the Channel to Dorsetshire. The marine series in England is at first fairly complete, but towards the north there appear, as we have already seen, intercalated beds of detrital material, and these continually increase in thickness as they approach the mouth of some river in the north. In Lincolnshire the influence of this river has extended so far that one of the intercalations is to be seen filling up channels of erosion in the underlying bed. In Yorkshire the thickness of the detrital sediments has enormously increased, and a considerable part of the marine middle Jurassic has been already replaced by them. Ramsay describes eight small seams of coal, each with an underclay, into which it

[1] Hébert assumed then that a retreat of the sea occurred after the Kelloway, i. e. a negative movement, but this view was probably based on the appearance of the beds which dovetail (?) into one another, and owing to the general denudation of the country form concentric zones; this arrangement was formerly regarded as an indication of the diminished extension of the sea; E. Hébert, Les Mers anciennes et leurs rivages dans le bassin de Paris, 8vo, Paris, 1857. The grey limestones of Venice were observed on the Sarthe; G. Boehm, Zeitschr. deutsch. geol. Ges., 1887, XXXIX, pp. 205–211.

[2] E. Eudes-Deslongchamps, Études sur les étages jurassiques inférieurs de la Normandie; Mém. Soc. Linn. Norm., 1865, XIV, pp. 1–296, in particular p. 279 et seq.

is said to send roots; these are interbedded in the plant-bearing series on the horizon of the Inferior Oolite. Finally, in the west of Scotland the whole series of the lower Oolites is resolved into a series of repeatedly alternating fluviatile and littoral beds, and it is not until the Oxfordian stage is reached that a marine deposit makes its appearance. In Sutherland the marine development begins again with the Kelloway [1].

Let us now turn our attention to the south.

The deep borings made from time to time in London and its neighbourhood have shown that in this locality the Lias and Inferior Oolite are absent; the beds immediately superposed on the Palaeozoic formations begin with the Bath Oolite, which is followed by the Kelloway and the other marine stages of the upper Jurassic. It is precisely the same with the series superimposed on the Devonian reef at Marquise, near Boulogne, which also begins with the Bath Oolite (II, p. 92).

Scania tells us nothing relevant; since the beds above the middle Lias have been removed by denudation, some loose fragments of the Kelloway have however been found.

The scanty exposures of Jurassic which present themselves beneath the Quaternary deposits along the north coast of Germany reveal the presence of Lias; and it has been reached by borings near Cammin. Still further east only higher beds are known, and in the boring at Purmallen near Memel the Kelloway beds were met with 95 meters beneath the surface, resting on red sandstone, which belongs probably to the Trias [2]. From here the Kelloway extends towards Popilany, on the Windau in Lithuania.

Thus the traces of a positive movement are manifest in the north of Scotland, beneath London, near Boulogne, and in the Baltic provinces; and we recognize a transgression beginning sometimes with the Oolite, sometimes with the Kelloway, and sometimes again with the Oxford stage, but in every case the Lias and Inferior Oolite are missing.

We will return now to Franconia.

The Trias deposits, as we trace them to the south, disappear on the western border of the Bohemian mass. The Lias is visible as far as Regensburg. As soon as we have passed the point where the Danube fault approaches the border of the ancient mass, that is, in the region of the marginal fracture which runs from Regensburg to Passau, the Jurassic series reappears, beginning with the lower stages of the Oolites. Beyond Passau every trace of the Jurassic has vanished, and it is not till we reach the far-distant locality of Olmütz, north of Brünn, that we discover

[1] J. W. Judd, The Geology of Rutland, Mem. Geol. Surv. England and Wales, 8vo, 1875, p. 33 et seq.; A. C. Ramsay, The Physical Geology and Geography of Great Britain, 5th ed., 8vo, 1878, p. 194.

[2] C. Grewingk, Das Bohrloch von Purmallen bei Memel; Sitzber. nat. Gesell. Dorpat, 105. Sitzung, 8vo, 1878.

lying upon the Devonian a patch of Jurassic, the lowermost beds of which, according to Neumayr and Uhlig, correspond to the upper Bathonian and the Kelloway [1].

Again for a great distance every trace of Jurassic is absent from the border of the ancient mass, and it does not reappear until we reach the neighbourhood of Cracow. Here and in the adjacent parts of Poland the stratigraphical relations are very remarkable. The Trias is present; the Rhaetic series is represented in one locality by plant-bearing beds; the Lias is missing; sandstones and clays occur containing marine fossils of the lower stages of the Oolites. At Balin, west of Cracow, the faunas of the Bath Oolite and Kelloway are richly represented, but it is the Kelloway stage alone which is continued towards the east together with the upper series of the Jurassic.

Next, let us enter Russia, and take for our guidance the works of Nikitin [2].

The transgression begins in Poland with the lower Kelloway; this stage is found in the government of Kiev; in Ekaterinoslav, Kursk, and Orel, the Kelloway has not yet been subdivided; the lower Kelloway also occurs at Elatma in the government of Tambov, in Riazan, in the north-west of Simbirsk, and in parts of Nishni Novgorod; it runs through the east of Kostroma into the basins of the Vytchegda and the Petchora, and thus reaches the Arctic Ocean. At the same time it extends through the east and south-east from Samara to Orenburg.

Contemplating this long and comparatively narrow zone of lower Kelloway we are led to conclude that the sea must have entered the eroded basin of a great river. The extension of the Jurassic sea did not cease with this stage, however; the middle Kelloway extends still further, and enters the governments of Moscow, Tver, and Yaroslav. To the west of Kostroma the series begins with the upper Kelloway or the lower Oxfordian [3]. At Kharkov the marine series, resting on plant-bearing beds, does not begin before the lower Oxfordian.

We will now leave Europe, to examine the far-distant and isolated patches of Jurassic which are presented by the table-lands of Africa and India.

[1] V. Uhlig, Die Jurabildungen in der Umgebung von Brünn; Beitr. pal. Geol. Oest.-Ung., edited by E. v. Mojsisovics and M. Neumayr, 4to, 1882, I, p. 130. These are the 'beds of Zeitlarn' of the neighbourhood of Ortenburg, at the same time the equivalents of the beds of Balin near Cracow.

[2] S. Nikitin, Ueber die Beziehungen zwischen der russischen und der westeuropäischen Juraformation, Neues Jahrb. Min., 1886, II, pp. 205-245; Neumayr, op. cit., 1887, I, pp. 70-88.

[3] S. Nikitin, Die Cephalopodenfauna der Jurabildungen des Gouvernements Kostroma, Verh. russ.-k. min. Ges. St. Petersburg, 1884, p. 74; and Allgemeine geologische Karte von Russland, Blatt 71, Mém. Com. géol. Russie, II, No. 1, 1885, p. 200.

At the south foot of the Great Hermon, near Medjel-esh-Shems, in Syria, the Jurassic system is limited to a very restricted area. The lowest visible member corresponds, according to Noetling, with the lower Oxfordian [1].

The nearest locality at which the Jurassic is next known to crop out from beneath the great mantle of Cretaceous limestone is Antalo, in the north-east of Abyssinia (I, p. 368). Aubry, who has somewhat recently travelled through the region in which the Blue Nile takes its rise, has furnished us with a detailed description of the geology. The sheet of Cretaceous limestone which covers the north-east of the Sahara does not extend into Abyssinia. It doubtless comes to an end near Khartoum, and the Archaean foundation is exposed throughout the Soudan, and according to Schweinfurth as far as the land of Niam-Niam. On the coast region it is visible as far as Massowah. This Archaean region is crowned by the high plateau of Abyssinia, consisting like the Sahara of flat-lying beds, but with a different stratified succession. The lowest member of the series is the thick *sandstone of Adigrat*, which extends in an arc from the foot of the table-land, probably starting from Adigrat and entering the interior as far as the sources of the Blue Nile. It is white or sometimes bluish, and is overlain by a yellowish crystalline limestone, which contains little bivalve shells and intercalated gypsum and dolomite. This is succeeded by the *Antalo limestone*, of Jurassic age, with marine fossils; Blandford discovered it at Antalo; it is visible again on the slopes of the valley of the upper course of the Blue Nile, and probably also in the valley of the Guibié in Kaffa. Above this rest beds of sandstone and gypsum, not so thick as the preceding, and the summit of the table-land, 2500 to 2800 meters above the sea, is formed of vast outflows of lava [2].

It is to this mantle of volcanic rocks that we are indebted in all probability for the preservation of the Jurassic succession in Abyssinia, represented in patches which are probably the remnants of once very extensive beds, and still even at the present day prolonged fairly far to the south. The marine series, according to the comparative studies of Douvillé, again begins with the Bathonian stage, and probably extends into the upper Jurassic as far as the horizon of the Kimmeridge.

To the southern extension of the Abyssinian series we may perhaps refer the exposures of upper Jurassic made known by Fraas and Beyrich at Mombassa on the coast of Suaheli (I, p. 400).

Another patch of flat-bedded marine Jurassic occurs at Cutch in India, there also partly protected by a more recent mantle of lava. It is con-

[1] Diener, Libanon, p. 25; F. Noetling, Der Jura am Hermon, 4to, Stuttgart, 1887.

[2] Aubry, Observations géologiques sur les pays Danakils, Somalis, le royaume du Choa et les Pays Gallas, Bull. Soc. géol. de Fr., 1886, 3e sér., XIV, pp. 201–222, geol. map; H. Douvillé, Examen des fossiles rapportés du Choa par M. Aubry, tom. cit., pp. 223–241.

tinued in a series of outliers far to the north-north-east in the plain of Rajputana (I, p. 414). Waagen's investigations show that the lowest member of this marine series, the Putchum group, also corresponds to the Bath Oolite; Douvillé has pointed out the resemblance of the Antalo limestone of Abyssinia to this group. Above it comes the Kelloway stage with *Stephanoceras macrocephalum*, and then a further series of marine stages presenting a most remarkable correspondence with the upper Jurassic of Europe. They are probably continued into the Salt range [1].

It is unnecessary to repeat what has already been said above regarding the less exactly known beds, probably of middle Jurassic age, which occur in Madagascar and on the east coast of India; I will only recall the fact that in West Australia the lowest marine deposits so far known also belong to the middle Jurassic (II, p. 189).

FIG. 28. *The valley of the Blue Nile* (after Aubry).

1. Volcanic rocks, 300 meters thick; 2. Yellowish crystalline limestone with Trigonia, 100 meters; 3. Grey marly limestone with *Modiola aspera*, Terebratula, Ceromya, 400 meters; 4. Yellowish crystalline limestones, with layers of dolomite, gypsum, and small bivalve shells, 200 meters; 5. White and blue sandstone, sometimes micaceous, with intercalations of green and variegated clay, 500 meters.

The results of our inquiry may be summarized as follows:—

At the beginning of the Rhaetic period the sea, in the region we have had under consideration, occupied a narrow area confined to a part of the Alps and the great ranges of Asia. Its level rose in Europe by a series of oscillations; its waters extended finally over a great part of central Europe. The oscillations persisted throughout the Lias; at the opening days of the Lias the domain of the sea was diminished, it was then enlarged and again reduced. It gained nothing in the lower stages of the middle Jurassic; but, with the advent of the Bathonian, which no doubt is not over sharply separated by its fauna from the Kelloway stage, the strand-line rose far and wide. The Bathonian lies on the downthrown Armorican arc beneath the soil of London, and on the Devonian at Boulogne; with it commences the great transgression over Abyssinia and the north-west of India. The boundary of the sea enlarged still further during the deposition of the

[1] W. Waagen, Jurassic Fauna of Kutch: I. The Cephalopoda; Mem. Geol. Surv. India, ser. IX, 1, 1873, p. 225.

Kelloway; in the extreme north of Scotland this lies on the fluviatile coal-bearing beds of Sutherland, it extends over the lower Jurassic stages of Pomerania, proceeding towards Memel and as far as Lithuania; and while the Lias of Franconia already comes to an end at Regensburg and the other stages of the middle Jurassic disappear in their turn, the sea of the lower Kelloway stage extended from Poland past Kiev, forming a long belt on the western side of the Ural and so reached the Arctic Ocean; at the same time, passing Orenburg, it encroached on the eastern side of that chain. At this epoch the Jurassic sea extended from the Petchora on the one hand to Sutherland on the other, to Abyssinia and Cutch, and much further still to the south and south-east. Withal the transgressive beds have preserved a horizontality as undisturbed on the banks of the Petchora as on the Blue Nile; and *Stephanoceras macrocephalum* maintains its horizon in the Kelloway from Brora in Sutherland to Cutch in India.

This extraordinary extension did not, however, mark the culmination of the positive movement; the coasts became increasingly remote, and this renders the determination of the new transgressions more and more difficult. The succeeding stages occupy, as far as can be seen, not only the whole region covered by the Bathonian and Kelloway, but in Europe they even extend beyond it.

Near Olmütz the Kelloway stage and lower Oxfordian reached the summits of the Devonian zone of the Sudetes; the upper Oxfordian and the lower Kimmeridgian ascended over the summit of the Bohemian mass and advanced across it into Saxony. Some slight remains of these transgressive deposits are now to be seen pinched in by the reversed fault which borders the southern edge of the Riesengebirge and the Isergebirge (I, p. 212).

In like manner, during the Kimmeridge epoch the sea covered that southern part of the Russian Platform which is cut through by the upper Dniestr (I, p. 181) in eastern Galicia, and extended over the Devonian red sandstone at the same time; it also reached the Dobrudja and deposited the horizontal limestone beds of the Kimmeridge on the upturned green schists of the mountain fragments of Matchin, Hirsova, and Chernavoda, extending as far as the Black sea; the limestone beds in all probability proceed still further beneath the Bulgarian plain (I, p. 475).

The investigations of Russian geologists lend support to the conjecture that in this case also the transgression of the lower Kelloway does not mark the highest level attained by the strand. We have already mentioned the later transgressions which seem to have occurred during the upper Kelloway and the Oxfordian. Whether the Kimmeridge stage covered great surfaces in Russia as it did in Galicia and on the lower Danube, extending beyond the limits of the Oxfordian, is however not known. This stage, as we shall see directly, marks the last recognized sub-

mergence known to have occurred before a great change of conditions set in, and it may therefore have been exposed to denudation in a still higher degree than the other stages. Pavlow, who has rendered such admirable service by his studies of the Kimmeridge in Russia, describes its occurrence at several localities in Simbirsk, as well as in the neighbourhood of Orenburg; it also occurs according to Gourow on the shores of the Donetz, and according to Levisson-Lessing at Nishni Novgorod. The fauna presents precisely the same characters as in the contemporaneous deposits of western Europe; *Exogyra virgula*, the little oyster so abundant in the Jura as to have led to the creation of an independent sub-group, the 'Virgulian,' and well known also in the Kimmeridge of Spain, England, the whole of the north of France and Hanover, as well as in the platy limestones of Ulm, now likewise appears in Poland and in the south-east of Russia in company with many other characteristic species of the Kimmeridge fauna of western Europe[1].

With the close of the Kimmeridge a complete change of conditions set in and affected the whole of Europe. Everywhere the sea receded. In Russia a new marine fauna, alien to the west of Europe, made its appearance, advancing from the north; it marks the *Volga stage*. In India the case is similar. Above the Katrol sandstone, which corresponds to the European Kimmeridge, plant-bearing beds occur; then species of a non-European fauna present themselves, proceeding out of the south; this is the fauna of the *Uitenhage series* of southern Africa.

We will now briefly review, so far as the evidence, in many respects very incomplete, permits, the emergence of a part of central Europe, and then the fresh transgressions, first coming from the north, and then finally from the south.

4. *Negative phase and the beginning of the Cretaceous period.* The extent and thickness of the fresh-water deposits which occur in Europe at the limit of the Jurassic and Cretaceous systems are too great not to have given rise to frequent discussions of a general nature. In 1872, R. Godwin-Austen, in giving a general account of these beds, offered some very suggestive remarks, which strongly recall those ideas on the succession of sediments in cycles to which we have made frequent reference. He believed that we could recognize in the northern hemisphere a recurrence of the same physical conditions after extremely long intervals of time. The marine series is again and again interrupted, over large areas, by continental deposits, like the Old Red sandstone for instance, the Coal-measures of the Carboniferous system, and the fresh-water deposits of the Weald.

[1] A. Pavlow, Note sur l'histoire de la faune Kimmeridgienne de la Russie, Univ. de Moscou, 8vo, 1886, 16 pp.; by the same, Les Ammonites de la zone à Aspidoceras acanthicum de l'est de la Russie, Mém. Com. géol. Russie, II, No. 3, 1886.

In support of his views Godwin-Austen appealed to several of the Wealden areas. A great lake covered the south-east of England, extending over Kent, Sussex, and Hants; it was continued across the Channel into the Boulonnais, and has left its traces in Oxfordshire and the isle of Wight. Godwin-Austen gave as the minimum size of this lake a length of 190 kilometers taken from Portland to beyond Aylesbury, and a breadth of 320 kilometers from Portland to the Boulonnais. Taking into account some small patches of Wealden in the anticlinal of the Pays de Bray, we obtain for the line from Wiltshire to beyond Beauvais a length of 400 kilometers. Other traces of the deposit have also been found in the departments of the Aube and the Jura. In the Charentes another lake existed about as large as lake Ladoga. A third in north Germany, about 190 kilometers in length, reached from Ibbenbühren through Osnabrück to Hanover and beyond. Finally, certain isolated patches of plant-bearing beds lying on the Belgian coal-field are also assigned to the Wealden series[1].

Subsequent observations have brought to light many new facts, and with their aid I will now attempt to trace in broad outline the course of events in western Europe.

The sea reigned over the whole region of the Alps and the Carpathians during this period[2]. Deposits representing the Weald are known in Spain and Portugal, and we must not omit to take them into account. But we will consider first the regions best known; these extend from the south-east of England to the Jura mountains, and from the west coast of France to the Harz. We shall depend for our most important data on Judd, Meyer, and Topley in England; H. Credner and Struckmann in Germany; Pellat, Loriol, Cotteau, Jaccard, and Maillard in the east of France and the Jura; and on Coquand in the west of France[3].

[1] R. Godwin-Austen, Address to the Geological Section: Rep. Brit. Assoc. Brighton, 1872, pp. 90–96.

[2] The only exception is perhaps mont Salvens, a chain of foothills of the Freiburg Alps, where blocks in the lower Neocomian and denudation of the upper Jurassic limestone beds may be quoted as indications of an interruption; V. Gilliéron, Aperçu géologique sur les Alpes de Fribourg, Beitr. geol. Karte Schweiz, XII, 1873, p. 108 et seq.

[3] J. W. Judd, On the Punfield Formation, Quart. Journ. Geol. Soc., 1871, XXVII, pp. 207–227; C. J. A. Meyer, On the Wealden as a fluvio-lacustrine formation, op. cit., 1872, XXVIII, pp. 243–255, and op. cit., XXIX, 1873, pp. 70–76; W. Topley, The Geology of the Weald, Mem. Geol. Surv., 1875, 8vo; H. Credner, Ueber die Gliederung der oberen Juraformation und der Wealdenbildung in N.-W. Deutschland, 8vo, Prag, 1863, et passim; C. Struckmann, Die Wealdenbildungen der Umgegend von Hannover, Hannover, 1880; by the same, Ueber den Parallelismus der hannover'schen und der englischen oberen Jurabildungen, Neues Jahrb. Min., 1881, pp. 77–102; by the same, Die Portland-Bildungen der Umgegend von Hannover, Zeitschr. deutsch. geol. Ges., 1887, XXXIX, pp. 32–67 et passim; P. de Loriol et E. Pellat, Monographie paléontologique et géologique de l'étage portlandien des environs de Boulogne-sur-Mer, Mém. Soc. phys. hist. nat. Genève, 1866, XIX, in particular p. 136 et seq.; P. de Loriol et G. Cotteau,

(*a*) The *Kimmeridge stage* extends from Portugal through the whole of the region considered here as far as Orenburg.

(*b*) In western Europe the Kimmeridge is succeeded by another marine member of the Jurassic, the *Portland stage*. This always lies conformably on the Kimmeridge, but in Hanover, where its fauna is very varied, 74 per cent. of the lower Portland species are known in the preceding Kimmeridge beds. The limit between the stages is by no means well defined; some geologists do not admit its existence; the course of events was therefore fairly undisturbed. In the upper beds of the Portland the connexion with the Kimmeridge is less marked, and in England, as in Germany and the Jura, brackish-water species, or such as are less sensitive to a change in the composition of the water, to a certain extent predominate. In the Charente, as in England, Hanover, and the east of France and throughout the Jura, the shells of *Corbula inflexa* and *Cyrena rugosa* cover in millions what was once the flat bottom of a shallow sea, apparently somewhat less salt than the Ocean.

But on the upper Dniestr we again discover a whole series of Portland fossils, including abundant examples of *Corbula inflexa*; and the facts elicited by Alth in his study of this fauna forbid us to assume that a barrier separating eastern and western Europe was in existence at this time[1].

We have now reached the upper limit of the Portland represented by the beds which are known in Hanover as the 'Einbeckhäuser Plattenkalk.'

At this point the great change set in.

(*c*) The sea, which extended beyond the Volga at the time of the Kimmeridge, and at least as far as the Dniestr during the Portland, was now so closely restricted that it did not pass beyond the region of the Alps and Carpathians, and indeed did not retain its hold on the Jura. In the territory it had abandoned lagoons remained in which clay and gypsum, with here and there rock-salt, were deposited.

In England these gypsiferous beds, which are always very poor in organic remains, are never exposed at the surface; but when in 1874

Monographie paléontologique et géologique de l'étage portlandien du département de l'Yonne, Bull. Soc. sci. hist. nat. Yonne, 1868, 2e sér., I, in particular p. 241 et seq.; E. Pellat, Émersion du sud et de l'est du bassin parisien à la fin de la période jurassique, etc., Bull. Soc. géol. de Fr., 1875–1876, 3e sér., IV, pp. 364–369; by the same, Le Terrain jurassique moyen et supérieur du Bas-Boulonnais, op. cit., 1879–1880, 3e sér., VIII, pp. 647–699; Loriol et A. Jaccard, Étude géologique et paléontologique de la formation d'eau douce infracrétacée du Jura et en particulier de Villers-le-Lac, Mém. Soc. phys. hist. nat. Genève, 1865, XVIII; G. Maillard, Invertébrés du Purbeckien du Jura, Mém. Soc. paléont. Suisse, 1884, XI, 156 pp., map, supplement in 1885, XII; H. Coquand, Description physique. géologique, etc., du département de la Charente, 8vo, Besançon, I, 1858.

[1] A. von Alth, Die Versteinerungen des Nizniower Kalksteins; Beitr. paläont. Geol. Oesterr.-Ung., edited by Mojsisovics and Neumayr, 1882, I, p. 330.

a boring was made near the middle of the Weald, they were encountered with a thickness of over 100 feet. They lie at the bottom of a basin, probably as a lenticular mass, completely buried out of sight beneath more recent sediments[1].

In north Germany they are known as the Münder marls, and they are frequently exposed at the surface as a consequence of the folding which has affected this region. The salt-beds underneath the city of Hanover, which were passed through by a boring, belong to this series. The marls attain a thickness of over 300 meters. The resemblance they bear to the Keuper has been pointed out by Struckmann.

A map of the Purbeck deposits in the Jura constructed by Maillard shows clearly that the course of events was the same there as in England. Gypsiferous marls, but only 3 or 4 meters thick, were deposited above the Portland over a part of the region now occupied by the Jura mountains, chiefly between the Doubs and the lake of Neuchâtel, and somewhat further to the north-east and south-west; but the succeeding deposits have a much wider extension, particularly towards the south-west, and if the region had not been folded, the gypsum would form a lens buried out of sight as in England.

Far to the west also, on the Charente, the gypsum has been laid down over the Portland. In this case, we have before us only part of a basin; the rest is concealed, on the one hand by the Atlantic Ocean, on the other by the transgression of the middle Cretaceous. It corresponds to the southern border of the Armorican horst, which is followed by the several members of the Mesozoic series in such a manner that successively younger members make their appearance as we proceed to the south or south-west. Above the Portland lies first a bed of cavernous limestone, about 1·6 meters thick, then 35 to 40 meters of gypsum accompanied by clay, with fish scales and fragments of wood. This bed of gypsum crops out in a zone striking to the north-north-west, from Châteauneuf west of Angoulême for a distance of 40 kilometers, and it may be traced in isolated exposures through Rochefort to the point de Chassiron, the northernmost promontory of the island of Oléron; so that its total length is more than 100 kilometers. The Gironde and the Atlantic conceal the greater part of this basin, and its outline is unknown.

The remarkable negative movement, which introduced such a complete change of conditions, also brought about the separation of eastern from

[1] It is true that by very close observation we may recognize the border of the synclinal of gypsum, sometimes indicated by corrosion of the surface of the Portland, sometimes as a thin layer of clay, or otherwise; see Blake, Quart. Journ. Geol. Soc., 1880, XXXVI, p. 221; Andrews, op. cit., 1881, XXXVII, p. 249, also Girardot, Bull. Soc. géol. de Fr., 1884–1885, 3e sér., p. 755. Perhaps the so-called middle Portlandian of Boulogne is to be referred here.

western Europe, and for a considerable interval each of these regions was the scene of independent events. This episode corresponds with *the lower part of the Purbeck*. The division of Europe marks its advent.

(*d*) The basins in which the gypsum was deposited began to be refilled.

In the Jura the sediments of this new stage, which consist of limestone and marl, extend from Biel to the south-west through the whole mountain range and further still into the department of the Isère. They are sometimes separated from the underlying beds by a cavernous dolomite, and attain a thickness of only 4 or 5 meters. At their base is a layer containing a mixed fauna of fluviatile and brackish-water shells, then a fresh-water bed, and above that again brackish-water layers. The upper brackish-water bed is, however, of but trifling extent, and appears, at least according to existing observations, scarcely to pass beyond the region of the gypsiferous clay, which lies deep below it. The fresh-water limestone-beds reappear outside the Jura near Baume on the Doubs, above Besançon, and near Gray on the Saône, so that a connexion appears to have existed with the eastern side of the Paris basin. But in the department of the Yonne the beds above the Portland are already absent, as well indeed as every trace of fresh-water deposits; and the marine lower Cretaceous rests directly on the marine Jurassic.

In north Germany, an imposing series of limestone beds, with marine, brackish, and fresh-water shells, was deposited during this period above the marls of Münde: they are known, owing to the abundant occurrence of *Serpula coacervata*, as the 'Serpulite.' The Serpulite also occurs near Boulogne and corresponds, in England, with that part of the Purbeck which lies above the gypsum. Oscillations were so frequent that Bristow distinguishes in this zone as developed in the isle of Purbeck, the remains of four ancient forests, eleven fresh-water beds, four brackish, and three marine beds, succeeding one another in repeated alternations.

On the Charente a limestone bed with fresh-water mollusca also occurs, the 'couche de deux pieds.'

The marine or brackish-water mollusca of these beds fully maintain the character of the lower beds; many species are common to both; we have here *an impoverished Jurassic fauna*.

The later transgressions show clearly that at this time all the western part of the Paris basin beyond the Pays de Bray was dry land, while in the east, from the Alps to England, the marine and fresh-water faunas variously alternate with each other.

(*e*) While the course of events had hitherto been uniform over vast areas, now local differences began to make their appearance.

The strand rose still further; the regions lying nearest the Alpine sea were submerged, and the new marine fauna of the Valengian or lower Neocomian advanced from the south over the region of the Jura. The sea

penetrated into France, but towards the west its deposits do not extend far past Vailly, north-west of Sancerre in the Cher. *In the north of France, however, and in the whole of England the marine deposits of the lower Neocomian are not known to occur*[1].

It is true the sea did not at once enter into permanent possession. Here and there occasional intercalations of fresh-water limestones may be met with, but these at length cease as the sea acquired undisputed dominion. Somewhat further north, in the Haute-Marne, a fresh-water bed is seen again at a much higher level, the Urgonian stage of the Cretaceous.

Still further north, in Hanover and in England, fresh water persisted longer than in the neighbourhood of the Alps; indeed it was at this period that the typical deposits of the Weald first began to be formed.

In north Germany the Serpulite is covered by a deposit of sandstone and shale, 200 meters thick, containing the remains of reptiles, fresh-water mollusca, such as Unio and Cyrena, and beds of coal, many times repeated in succession, as in the ancient Coal-measures. Tracks of animals on the surface of the sandstone beds show how the surface of the fresh-water lake gradually rose to a higher level, till it became stationary.

Similar sandstones occur in small patches near Boulogne; in England they lie above the Purbeck, as in Hanover, and contain numerous remains of the great Iguanodon and fragments of terrestrial plants. The series is known as the *Hastings sands*, and, as in Germany, the footprints of animals are found in it at various levels.

(*f*) In Hanover, as in England, there now follows the *upper Weald clay*. Again the influence of the sea began to make itself felt.

In north Germany this member attains a thickness of about 60 to 70 meters: by the side of numerous fluviatile mollusca, the brackish-water forms of the Serpulite reappear, and among them *Corbula inflexa*. This represents the still further impoverished Jurassic fauna, which during the period of the Hastings sands had continued to exist somewhere in lagoons. In England we meet with brackish-water intercalations in the fresh-water clay, and *Ostrea distorta* once more gives rise to a bed which occurs close to the summit of the Wealden. Thus under the most unfavourable conditions the last survivors of the Jurassic period have succeeded in maintaining their existence, a true relict fauna.

In England the thickness of the deposits increases rapidly towards the west, and reaches 2,000 feet in the beds above the Purbeck: possibly the clastic sediment came from that direction. In Belgium there may be seen

[1] Hébert has done admirable work in establishing these facts; an account of the conditions in France is given by Lapparent, Traité de géologie, 2e éd., p. 1034 et seq. Price (Proc. Geol. Assoc., 1875, IV, pp. 269–278) and Gardner (Geol. Mag., 1877, 2nd ser., IV, p. 377 et passim) conclude from the nature of the deposits that the Gault sea of England also became deeper.

here and there, resting on the Coal-measures, beneath the later beds of the middle Cretaceous transgression, patches of sand or clay which contain remains of plants. These are the remnants of deposits which accumulated in hollows of the ancient surface; in 1878 the mines of Santa Barbara, near Bernissart, not far from the French frontier, revealed, at a depth of 322 meters below the ground, a mass of clay faulted down into the Coal-measures; this contained several skeletons of Iguanodon, with associated fishes and plants of the same species as characterize the English Weald[1].

Brown clay containing plant remains occurs also on the limestone of Charente.

(*g*) The sea advanced again still further to the north, and the period of great lakes gradually came to an end. It is no longer the marine fauna of the Valengian or lower Neocomian which accompanies the transgression as in the Jura; but that of the middle Neocomian, the Hils or Hauterivian, as we meet with it in Germany. At the same time the north of France was submerged, and the south of England was reached by the sea, for the first marine intercalation of the Cretaceous lies very nearly on this horizon. But in England fresh water once more reappeared, and it was not till the following stage of the lower Cretaceous that the region of the ancient lake was at length permanently occupied by the sea. This stage begins with the Punfield beds, which correspond to the Urgonian of French geologists[2].

The positive movement proceeded in a series of oscillations. It first carried the lower Neocomian from the Alps across the region of the Jura to France. In the middle Neocomian, i.e. at the time of the Hils stage, a further transgression brought its waters over the north of France, the north of Germany, the north German Weald, and a large part of England. In the following or the Urgonian stage, the series of fresh-water deposits was brought to an end in England also. While the sea of the lower Cretaceous had already spread itself over the Purbeck area of the Jura, some brackish-water mollusca, the last remains of the Jurassic fauna, still persisted in the Wealden area of England and Germany, despite the northwards march of the sea[3]. Indeed, these Jurassic mollusca, already adapted by repeated oscillations to brackish-water conditions, were much better fitted to maintain their existence in the lakes and estuaries of the period than the new arrivals freshly introduced by the waters of the Cretaceous sea.

Having obtained these results, let us now cast a glance over the peninsula beyond the Pyrenees.

[1] Dupont, Bull. Acad. Roy. Belg., 1878, 2e sér., XLVI, p. 387.

[2] In Germany also some fresh-water mollusca occur in higher marine deposits; G. Boehm, Beiträge zur geognostischen Kenntniss der Hilsmulde, Zeitschr. deutsch. geol. Ges., Inaugural-Dissertation, Berlin, 1877, p. 10.

[3] This important conclusion was also drawn by Beyrich, Zeitschr. deutsch. geol. Ges., 1880; and Neumayr, Verh. k. k. geol. Reichs., 1880, p. 290.

We have found hitherto that we could most clearly represent the course of events by tracing them from the Alps through the Jura and on to the north-west as far as the English Weald. We will pursue a similar course in Spain, and follow the succession of the beds in a north-west direction from the Balearic isles to the Atlantic coast.

In the Balearic isles, which we regard as the probable continuation of the Betic cordillera, the stratified series, as in the cordillera itself, and as in the Alps, is chiefly of a pelagic character. Purely marine deposits represent the upper Jurassic, which is overlaid by the lower Neocomian. On the continent, we again meet with the lower Neocomian near Valencia, but further inland it is not yet known to occur; it is also absent in those parts of the Paris basin which are most remote from the Alps. On the other hand there appears on the coast, in the little mountain range of Atalayas de Alcala, near Castellon, a lithographic limestone with *Exogyra virgula*, and thus on the horizon of the Kimmeridge; it resembles the lithographic limestones which occur at the summit of the Jurassic in the south-east of France, and from Ulm to Solenhofen in Bavaria, but these probably represent the Portland as well as the Purbeck, and Gümbel has shown that in south Germany they bear the signs of numerous minor oscillations, such as under different conditions we were able to recognize in the English Purbeck. The next sediments which are known above the lithographic limestone of Atalayas belong not to the lower Neocomian, but to the Urgonian stage [1].

Further inland in Teruel, coal beds crop out, alternating near Utrillas, with marine sediments; their fauna precisely coincides with that of the Punfield beds, which are intercalated with the highest beds of the English Weald, and mark its close [2].

The fresh-water deposits of the Weald occur still further to the north-west in parts of Logroño and Burgos, extending as far as the valley of the Saja, in Santander, and attain the Atlantic coast. Palacios and Sanchez have described them in the southern part of this region; according to Calderon's account they attain a thickness of over 1,000 meters, and the largest of the areas they occupy covers 1,200 square kilometers; they may be subdivided into Hastings sand and Weald clay, as in England [3].

[1] H. Hermite, Études géologiques sur les îles Baléares, 8vo, Paris, 1879, p. 138; Coquand, Sur l'existence des étages coralliens, etc., dans la province de Castellon de la Plana, Bull. Soc. géol. de Fr., 1867, 2e sér., XXIV, pp. 462–471; C. W. Gümbel, Die geognostischen Verhältnisse des Ulmer Cementmergels, Sitzber. k. bayr. Akad., 1871, I, pp. 38–72.

[2] E. de Verneuil et G. de Lorière, Description des fossiles du Néocomien supérieur d'Utrillas, 4to, Paris, 1868; the correspondence is emphasized by Judd, Quart. Journ. Geol. Soc., 1871, XXVII, p. 224.

[3] P. Palacios y Raf. Sanchez, La formacion Wealdense en las provincias de Sorio y Logroño, Bol. Com. mapa geol. España, 1885, XII, pp. 109–140; S. Calderon, Note sur

The marine series of the Cretaceous begins everywhere in this part of Spain with the Urgonian, which, as Carez has shown, extends over Catalonia, north Arragon, Navarra, and Biscay [1].

The correspondence with central Europe is remarkable; the Balearic isles answer to the Alps, Santander to the south of England.

Let us next turn to Portugal.

Many years ago Sharpe described an 'infra-Cretaceous' series of fresh-water origin occurring in Portugal. Delgado recognized its correspondence with the Weald, and it was subsequently described by Ribeiro; it is shown on the geological map of Portugal as extending from Setubal to Cabo de Espichel, and in many larger and smaller areas north of the Tagus to Cabo Mondejo. Saemann correlated the upper parts of the Portuguese Jurassic with the Portland of Boulogne [2].

In the Serra de Cintra, according to Choffat, the Kimmeridge is surmounted by a thick series of limestone beds, which contain some of the species of the preceding fauna, and some fresh arrivals, including Cyrena. Then follows the Valengian, next the Hauterivian, i. e. the marine lower and middle Neocomian. But only 20 kilometers to the east, near Bellas, west-north-west of Lisbon, the Valengian is replaced in this series by a sandstone containing terrestrial plants and corresponding to the Weald [3].

The series of events is thus essentially the same from the Harz to the west coast of Portugal. Above the Portland, first the sea became shallow or was replaced by fresh water, next followed a chain of evaporating lagoons, extending from Hanover to the island of Oléron, and then great fresh-water lakes made their appearance over the area between Hanover and the west coast of Portugal. The sea, which at first had completely retired to the south, now, at the time of the lower Neocomian, extended over the north of France as far as the Cher; in Spain it only approached Valencia, and in Portugal passed over some districts in the west. In the Hils (Hauterivian) and the Urgonian, the strand-line continually advanced by oscillations until the whole region of the fresh-water lakes was entirely covered by the sea. In many places the fresh-water beds, and in Charente the gypsum also, strike out against the Atlantic Ocean, proving that at this epoch continental land extended beyond the existing coasts.

le terrain wealdien du nord de l'Espagne, Bull. Soc. géol. de Fr., 1886, 3e sér., XIV, pp. 405–407.

[1] L. Carez, Étude des terrains crétacés et tertiaires du nord de l'Espagne, 8vo, Paris, 1881, p. 147 et seq.

[2] D. Sharpe, On the Secondary District of Portugal which lies on the north of the Tagus, Quart. Journ. Geol. Soc., 1850, VI, pp. 134–201 (Sub-cretaceous Series); Ribeiro e Delgado, Carta geologica de Portugal, fol., 1876; Saemann in Loriol et Pellat, Étage portlandien de Boulogne, p. 184; C. Ribeiro, Breve noticia acerca da constituição physica e geológica da parte de Portugal comprensa entre os valles do Tejo e do Douro, Jorn. sci. math. Ac. R. Lisboa, 1870, II, pp. 243–252 and 353–369, in particular p. 249.

[3] Choffat, in Act. Soc. helv. sci. nat. réunie à Locle 1885, 8vo, Neufchâtel, 1886, p. 63.

5. *Further transgressions and intermixture of the Cretaceous faunas.* It will be seen from the foregoing that the maximum of the negative phase must be placed at the base of the gypsum and salt marls, between the Portland and the Purbeck, and from this time, in spite of all oscillations, the preponderance of the positive movement may be recognized up to the transgression of the Urgonian, which covers the whole of the Weald.

The greatest change in physical conditions did not therefore exactly coincide with the greatest change of the fauna, but slightly anticipated it, for the upper Purbeck contains a fauna which is still undoubtedly Jurassic.

First of all the question arises whether this negative phase may not find in some other part of the world a complementary positive phase. Indications of this are not far to seek. The Kimmeridge of the western region extends, as we have seen, through Poland to the Volga and beyond it. But even in west Poland, near Tomaszow, on the Pilica, Mikhalski has observed the vestiges of a sea alien to western Europe, viz. *the lower Volga stage* of Russian geologists (zone of *Perisphinctes virgatus*). Mikhalski has described it, and doubtless with truth, as the first indication of a great northern infra-Cretaceous transgression [1]. Nikitin places the Volga stage in the period of the English Weald.

Since a considerable number of species characteristic of the Portland of western Europe still occur in east Galicia, the separation of Russia from western Europe must be placed at the close of the Portland, i. e. precisely at that time when the deposition of the gypsiferous marls begins, or at the maximum of the negative phase in western Europe. While in the west and south the strand was in retreat, leaving behind the gypsiferous lagoons, in the north-east on the contrary it was advancing, on the one hand over Kostroma, Twer, Moscow, and Riasan, and on the other from Orenburg and Samara over Simbirsk.

The investigations of Russian geologists, who of late years have brought to light so many new facts in connexion with this subject, hardly permit us at present to trace in detail on the map the distribution of the several subdivisions of the Volga stage, but there appears to be no doubt that in the north of Asia a great transgression corresponds to this stage, particularly to its upper members. The area affected by this transgression includes, according to Nikitin, the region west of the lower Ob southwards as far as lat. 63° N., then a part of north Siberia, particularly the peninsula of Taimyr, down to Dudinskoj on the lower Yenisei, then down the lower course of all the rivers situated to the east as far as the Jana, but not so far south as the Arctic circle. There the deposits of the Volga rest in patches on the marine Trias. The Jurassic beds said to occur in regions

[1] A. Mikhalski, Notes sur les couches à *Perisphinctes virgatus* de la Pologne ; Bull. Com. géol. Russie, 1886, V, pp. 363, 456.

more to the south are more or less doubtful; the upper Volga beds, on the other hand, appear to occur on the Amur and the Bureja.

The Mesozoic deposits of Spitzbergen, which rest on the Trias, as well as those of east Greenland, have already been assigned, on the evidence of existing observations, to the Jurassic (II, p. 69); it must however be added that Lahusen, in his latest investigations of the upper Volga stage on the Yenisei and Lena, has observed much similarity between these beds and those of Spitzbergen and east Greenland [1].

The uncertainty as to the stratigraphical position of certain beds characterized only by Aucella, and the difference of opinion existing among palaeontologists on this point, render it impossible to extend these comparisons to the Aleutian islands or the Queen Charlotte islands, where the Volga stage is certainly represented. According to White it is very probable that the Aucella beds of California correspond with those of the north; possibly they extend to New Mexico [2]. In Arctic North America, however, and as far as cape Farewell, nothing similar is known. In west Greenland the lower Cretaceous is only represented by plant-bearing beds.

The genus Aucella can be traced from the north to the Lofoten islands, but it does not proceed further into the Atlantic.

Some indications of similar relations may be observed in the southern hemisphere.

In east Australia there is evidence of a Cretaceous transgression, which Neumayr places at about the horizon of the Aptian (II, p. 155). In the south-east of Cape Colony plant-bearing deposits, which include marine beds, the well-known Uitenhage series, rest on the older stratified formations (I, p. 399). Near Sripermatúr, on the east coast of Hindustan, some sandstones occur, which may be assigned to the Uitenhage horizon (I, p. 409). We now reach the Jurassic region of Cutch. The various stages of the European Jurassic may be distinguished up to the horizon of the Portland. The Umia group, which contains species common to the European Portland, is a sandstone 3,000 feet thick. The greater number of marine fossils, chiefly Portland species, occur in a calcareous conglomerate near its base; higher up, many terrestrial plants appear, and above the plants we meet with a few species of the Uitenhage stage. Here, therefore, the European Jurassic system is covered by the Uitenhage, a stage unknown to Europe; just as in Russia it is covered by the lower Volga stage, also with an alien fauna. The Uitenhage fauna has come from the south, the Volgian from the north. To complete the correspondence, we find in Cutch, above the

[1] J. Lahusen, Die Inoceramen-Schichten an dem Olenek und der Lena, Mém. Acad. Imp. Sci. Saint-Pétersb., 1868, XXXIII, No. 7. *Amaltheus Nathorsti*, Lundgr., of Spitzbergen is also said to occur in the upper Volga stage on the Bureja.

[2] C. A. White, On the Mesozoic and Cenozoic Palaeontology of California; Bull. U.S. Geol. Surv. Territories, No. 15, 1885, p. 22 et seq.

Uitenhage stage, the Aptian, with its European fauna (*Hoplites Deshayesii*), and the same stage (also containing *H. Deshayesii*) rests in Simbirsk, according to Nikitin, on the Volga stage. A species belonging to the Aptian stage of Australia occurs with the European Aptian in Cutch.

We have then in Simbirsk, first the European Jurassic, next the northern Volga stage, and then the European Aptian stage; and similarly in Cutch, first the European Jurassic, then traces of the southern Uitenhage stage, and last traces of the European Aptian stage.

We have now advanced far enough to return to Europe, and there to trace the events which mark the limit between the Jurassic and Cretaceous systems, as well as certain phenomena in the succession and composition of the marine Cretaceous fauna.

The marine Jurassic fauna, so far as we can trace its history, did not give rise to the marine fauna which succeeds it. Some of the pelagic forms of the Alpine area may have contributed direct descendants, but the fauna of moderate depths was destroyed, first by the extensive retreat of the sea, and next by fresh-water conditions; some brackish-water species may have been derived from marine forms, and have persisted for awhile; but the new marine faunas came, for the greater part, from elsewhere.

The Valengian of the lower Neocomian, which extends but a slight distance beyond the pelagic region of the Alps, does not contain a rich fauna, and shows foreign affinities.

The next stage is the Hils or Hauterivian, which possesses a much wider distribution. When Neumayr and Uhlig described the Ammonites of the Hils in 1881, they showed much more clearly than had been done before the presence of northern elements in this member of the Cretaceous formation. Subsequent investigators, among others Weerth and Marie Pavlow, have shown that relations exist between the Hils fauna and forms occurring in Russia; indeed some species of the Volga fauna appear in the Hils. But Neumayr and Uhlig have shown that a close resemblance also exists between some forms of the Hils and the Uitenhage fauna. The period of transgression was also a period of intermixture of faunas, and both northern and southern elements make their appearance in Europe. The isolation of the north-east by the negative movement, during the continuance of which the development of the north Volga fauna was in progress, now came to an end [1].

[1] M. Neumayr and V. Uhlig, Ueber Ammonitiden aus den Hilsbildungen Nord-Deutschlands, Paläontographica, 1881, XXVII, p. 74; O. Weerth, Die Fauna des Neocomsandsteins im Teutoburger Walde, Paläont. Abh., edited by Dames and Kayser, 1884, II; Marie Pavlow, Les Ammonites du Groupe *Olcostophanus versicolor*, Bull. Soc. nat. Moscou, 1886, LXII, pp. 27–43. Neumayr had inferred the northern transgression even much earlier, not only from the marine faunas, but also from Sandberger's statement that in the upper Weald the tropical lacustrine fauna is replaced by one of North American character; Verh. k. k. geol. Reichs., 1873, p. 290.

Hitherto but little has been said of the lower Cretaceous deposits of the Alps, which succeed each other in unbroken pelagic development, because indeed general transgressions or regressions can seldom be demonstrated in folded mountains; the case of the Purbeck in the Jura mountains worked out by Maillard is a rare exception. On the other hand, we must not neglect to take into account the character of the faunas. If we look for the pelagic representatives of the littoral deposits we find, immediately above the equivalents of the Hils or Hauterivian, the *Barrêmian* stage in the lower Rhone valley, and the *Wernsdorf shales* in the Carpathians, and again a new element appears in their fauna. The rich lower Cretaceous fauna of Santa Fé de Bogota in Columbia, described in detail by Karsten, sends numerous representatives into this stage. Coquand and d'Orbigny recognized them in the Barrêmian of France, Hohenegger in the Carpathians; Uhlig has shown the correspondence which exists between the far-distant faunas of Bogota, the lower Rhone valley, and the Carpathians. The genus Pulchellia is as typical of this immigration into Europe, as Holcostephanus of the preceding transgression [1].

In the Aptian stage finally a uniform flora appears to have extended from Russia across Europe, and the few species so far known from India indicate that they too once extended over this region.

Thus towards the close of the Jurassic period Europe once more emerges from the sea, to again disappear beneath successive advancing transgressions. The Alpine region remained constantly submerged. The maximum of physical change, between the Portland and Purbeck, did not coincide, in central Europe, with the maximum change in the fauna. Its chief effect was to produce increased isolation and to prepare the way for the extinction of the sublittoral elements of the fauna. The effects of the succeeding transgressions on the faunas vary in importance in proportion as, in each case, they establish new marine communications, and thereby facilitate or promote fresh immigrations.

Nikitin has pointed out that in Russia the highest degree of independence occurred at the time of the Volga stage, but afterwards in the epoch of the Gault the universality of the fauna was 'gradually re-established even in the most distant regions.' Neumayr has arrived at similar results [2]. Phenomena of this kind cannot be explained by oscillations of the continents.

The distinction between the Pacific and Atlantic regions now appears still more sharply than before. Lower Cretaceous beds are known at many localities on the east coast of America, from the Aleutian islands to cape

[1] V. Uhlig, Die Cephalopodenfauna der Wernsdorfer Schichten; Denkschr. k. Akad. Wiss. Wien, 1883, XLVI, p. 158.

[2] Nikitin, tom. cit., p. 239; Neumayr in numerous publications, in particular Erdgeschichte, II, 1887, p. 366, and Neues Jahrb. Min., 1887, II, p. 279.

Horn; also in New Zealand and Australia. On the border of the Pacific they are folded; in the interior of Australia they lie flat. But on the Atlantic coasts, except in the case of Europe, we seek in vain for representatives of any of these deposits. Even in Europe the Weald advances with its fresh-water deposits right up to the brink of the Ocean. Nevertheless a communication of the lower Cretaceous seas of Europe with those of the west of South America is indicated by their fauna. This communication, however, can only have existed in the vicinity of those parts of the coast which are constructed on the Pacific type, i. e. between the existing Mediterranean and the West Indies.

6. *The Cenomanian transgression.* As the long series of intermittent positive movements from the Rhaetic stage on through the Lias was only the forerunner, as it were, of the great transgression of the Bathonian stage and the Kelloway, so all the oscillations of the lower Cretaceous seas in Europe yet mentioned were only the preliminary warnings of a transgression of far greater importance, especially distinguished by the fact that *it affected the Atlantic coasts also.*

This transgression embraces the Cenomanian, Turonian, and Senonian; there are indications that its greatest extension coincided with the Senonian. Since this subject has been discussed elsewhere we will now only give a summary of the most important results [1].

The Cenomanian transgression has left its traces on the summit of the Spanish meseta; thence it may be followed to the north, across France, and into the north of Scotland, where its deposits may be seen at several localities. Isolated patches of the Senonian have been revealed by dredging off the Norwegian coast, up to the highest latitudes (II, p. 67). The transgressive Cretaceous is to be seen on the summit of the Bohemian mass, as far as the Bavarian Jura, and further north in numerous patches in Denmark and as far as Scania. Signs of the transgression also occur in a part of the Baltic. It extended across Poland, and Karpinsky, who has clearly recognized the difference in extension of the lower Cretaceous and this new transgression, describes its northern limit as having passed somewhat north of Vilna and Mohilew through Kaluga towards Moscow, and then somewhat north of Simbirsk and Samara towards Orenberg [2]. Thus the northern half of Russia remained uncovered by the sea; the southern outrunners of the Ural on the other hand were submerged, but Herr Karpinsky has kindly informed me of the remarkable discovery, made by Herr Fedoroff, that Cretaceous beds with Baculites exist beyond the Ural on the northern Sosswa in lat. 62° 30′ N. These Baculite beds rest upon fossiliferous strata, probably belonging to the upper Volga stage, and the whole succession is horizontal.

[1] Entstehung der Alpen, pp. 104–117.

[2] Karpinsky, Uebersicht der physiko-geographischen Verhältnisse, etc., fig. 9.

The Cenomanian sea extended over the whole region of the Caspian and the Ural; and according to Romanowski and Musketow it covered the Kizil-Kum and all the plains of Turania up to the great mountain chain, which no sea appears to have reached since the Palaeozoic aera; for the lower members of the Mesozoic series are represented in it either by coal-bearing beds or not at all [1]. The Cenomanian sea continued further into the basin of the Tarym, on the south side of which Stoliczka encountered, to his great astonishment, evidence of the Cretaceous transgression.

The middle and upper Cretaceous also cover the whole region of the central Mediterranean and even extend beyond it. Represented chiefly by hard limestone, they pass from the south of Europe across Syria, cover the whole eastern half of the Sahara and Arabia, and penetrate into the valley of the Narbada, thus reaching India.

Marine intercalations of the Senonian are found in the plant-bearing beds of Disco in lat. 70° N. Patches of middle Cretaceous also occur on the east coast of the United States, as in New Jersey, for example. From the gulf of Mexico the transgression extended into the country to the west of the sierra Madre; it reached Chihuahua, Praesidio del Norte, and the Ilano Estacado of Texas, and extended into the prairies through Kansas, Nebraska, and Dakota into the basins of the Saskatchewan and the Mackenzie up to lat. 65° N. and perhaps even to the Arctic Ocean.

At the same time the Cenomanian sea entered the valley of the Amazon, crossed the whole breadth of South America to the Andes, and probably reached the Pacific Ocean. Its sediments are seen at Piauhy, Ceara, and as far as Bahia (I, p. 510). In the south the Cretaceous forms the underlying rock of the Pampas, and middle Cretaceous fossils are found up to lat. 53° 30′ S. in Patagonia (I, p. 526).

On the west coast of Africa from near the equator to Mossamides (II, p. 134) deposits of the lower Cenomanian occur, which some observers refer to the Gault, but on the east coast they reappear with a different fauna, which has been distinguished as the Indian type. This fauna accompanies the transgression on the coast of Natal, again on the coast of Trichinopoli, and finally in the Shillong plateau (I, p. 411). West Australia is covered by transgressive middle Cretaceous beds, concerning which, however, we unfortunately possess but scanty information.

The Pacific region has suffered so much from compression and folding that it is unusually difficult to prove the existence of transgressions within it. In Yezo and Saghalin the Cretaceous of Indian type reappears, probably in transgression (II, p. 182); middle Cretaceous lies unconformably and horizontal in the foot-hills of California (I, p. 584).

[1] G. Romanowski, Materialien zur Geologie von Turkestan, German edition, 4to, St. Petersburg, 1880, p. 43.

Thus the sea of the latter half of the Cretaceous period covered Turania and Irania, Arabia and the Sahara, the prairie-land of North America and the great valleys of the Amazon and Parana. On the other hand a definite area may be recognized which does not appear to have been reached by the inundation. This embraces Greenland, Spitzbergen, perhaps the north of Scandinavia, northern Russia, Siberia, and the whole of northern China. The conjecture might have been hazarded that the Cretaceous formation had been removed from this region by ice, but the Tertiary leaf-bearing beds are everywhere present, and rest on the Jurassic or Volga stage in east Greenland and Spitzbergen, while the middle or upper Cretaceous is not to be seen; it is true, however, the Baculite beds of the Sosswa lie within this region. A great part of Gondwána land, broken up even so early as this period, also remained above water, for we see in the east as in the west of Africa, that the Cretaceous beds only rest against the sides of the plateau, or, as in India, at most extend into the valley of the Narbada, without reaching the plateau itself. West Australia, on the other hand, was submerged.

However this may be, it would appear, according to the present state of our knowledge, that a considerable area of dry land extended around the north pole, particularly on the Asiatic side, and more especially in the direction of northern China. In the lower Cretaceous period the Volga stage came from the north southwards, the Uitenhage stage from the south northwards, both from polar regions. The middle and upper Cretaceous transgressions, on the other hand, chiefly affected the equatorial and temperate zones; it is probable that the sediments in the valley of the Mackenzie, the marine intercalations between the plant-bearing beds of Disco, and the deposits in the deep water off the coast of Norway represent outrunning arms of the sea. Whether this explanation will apply to the beds exposed on the Sosswa, future investigation must decide.

The great extension of the middle and upper Cretaceous seas was followed after the Senonian, as it was after the Portlandian, by an extraordinary retreat. This negative phase will be discussed in connexion with the Eocene.

7. *Survey of the Mesozoic seas.* The transgressions covering the continents of the Mesozoic period, whether they came from the poles or the equator, nowhere left sediments on the continents which would indicate abyssal depths. The Kelloway, the transgressive beds of the lower Cretaceous, and the Cenomanian are composed of clastic materials, accompanied as a rule by numerous organic remains, and it is only in the Senonian that a sea of any considerable depth can be supposed to have covered northern Europe. The Callovian of Russia and the Cretaceous mantle of the upper valley of the Elbe may be cited as examples. These mark merely temporary submergence of the land, and must not be confused with the great persistent abysses of the Ocean.

Our geographical maps show the outlines of existing seas, but some of these are very deep; others, on the contrary, as for instance the Arctic Ocean, are of very trifling depth. A knowledge of the outlines does not imply therefore a knowledge of the position of the great depths.

It is clear that the Trias deposits around the Pacific Ocean are represented in the folded chains; in the Indian Ocean the evidence of a transgressive border or overlap only begins with the middle Jurassic, and in the Atlantic region with the middle Cretaceous. In the Indian and Atlantic Oceans we observe besides that the border is not folded.

In that part of the Arctic Ocean which washes the coasts of Asia as far as the east coast of Greenland, and the Lofoten islands, but not beyond, certain features appear in common with the Pacific region. As far as Spitzbergen the Trias is similarly present, but in Spitzbergen it is not folded. Certain parts of the Jurassic system as well as the Volga stage appear in these parts of the Arctic regions, but the middle and upper Cretaceous are absent. Baffin bay, on the other hand, shares the characters of the Atlantic Ocean: the only marine deposit of western Greenland belongs to the upper Cretaceous.

We will now leave the shore of the Ocean and cast a glance at the stratified series of the Silakank in the Himaláya (I, p. 437). Where, as in this case, the Mesozoic beds succeed each other uninterruptedly in persistent pelagic development, for a thickness of thousands of feet, and even overlie a similar series of Palaeozoic beds, we seem forced to conclude that a deep and long persistent sea lay in the midst of the existing continent, and that it was brought to an end by the accumulation of its own sediments, by negative movements of the strand, and by the folding of the mountains. The eastern Alps afford us examples which are no less striking, and we must admit with Neumayr the existence of a central Mediterranean, which extended as early as the Trias from Asia across the south of Europe, over part of the region of the existing Mediterranean to beyond Gibraltar. That this sea passed across the Atlantic even before the deposition of the Cenomanian on the coasts around this Ocean is proved by indications in the Jura, and by characters even more definite in the lower Cretaceous marine fauna of Bogota.

The enlargement of this central Mediterranean, which originally extended parallel with the equator, may have subsequently given birth to the Atlantic by a succession of subsidences. Even in the Weald the fresh-water beds on the coast of Portugal and north Spain are cut off abruptly by the sea. The occurrence in the West Indian islands of many corals characteristic of the Turonian of Europe presupposes a coast-line, or at least a number of fairly large islands in the midst of the existing Ocean, to render the migration of the corals possible (I, p. 281).

It is, therefore, probable that even before the time of the Cenomanian

the ancient sea which stretched from Europe to the West Indies had experienced a considerable extension by the addition of fresh subsidences, and that from this extended region the Cenomanian transgressions proceeded, but at the same time it is equally probable that since then an increase has taken place by the occurrence of yet other subsidences.

The mutual encroachment of transgressions and tectonic processes renders a complete solution extremely difficult, and we are compelled to express ourselves with great reserve. Steinmann met with Cretaceous sandstone in Bolivia, lying in horizontal beds at a height of 4,000 metres above the sea. He was led to conclude that since its formation 'the surface of the sea must have moved so much nearer to the centre of the earth[1].'

For the present we may content ourselves with the conclusion that the existing oceans are of different ages, and turn our attention to another question.

In the opening pages of this book the outlines of the continents, narrowing away to the south, were described as the most striking feature on the map of the world; and it was further observed (I, p. 5) that any attempt to comprehend the movements and changes of form of the earth's crust must take into account these great features of the planetary surface.

The wedge-shaped form appears in four typical cases: in South America, South Africa, India and Greenland, and thus in the most diverse latitudes. Other examples of less importance might be cited, such as the peninsula of Sinai and the Crimea; even in the interior of the continents similar outlines may be seen, as for example in the Bohemian mass.

South America, formed in the west and south by the extremity of a curved mountain range, in the east of alluvial land, deviates completely from the other examples in structure, and may be left out of account. The three remaining examples are table-lands. Greenland is a radial slice of the Atlantic, the table-land of Old Red sandstone: India is a similar segment of the Gondwána table-land: South Africa is another part of the same table-land.

Greenland exhibits beds of the Asiatic Arctic type resting against its eastern coast, and beds of the Atlantic type on its western coast. The coast-lines of different seas meet in cape Farewell. These facts cannot be explained by the elevation theory. Greenland is a horst of the first order between two or more sunken areas of different age.

India rises in the same way between the bay of Bengal and the Arabian sea, and South Africa between the two Oceans: in these cases the distribution of the Gondwána formations and the lie of the thick plant-bearing beds, which in the case of Africa boldly face the sea, are sufficient proof

[1] Steinmann, Compte rendu, 69me Session de la Société helvétienne; Arch. sci. phys. et nat. Genève, 1886, p. 93.

of the fracture. The various deposits resting against these masses indicate the age of the different coast-lines (I, p. 418). The elevation theory cannot explain how a table-land of plant-bearing beds, such as this, which has never been covered by marine deposits, could have been raised from the depths of the sea.

In like manner the peninsula of Sinai, the Crimea, and the Bohemian mass are bounded on the south by the convergent edges of regions of subsidence.

Thus, as our knowledge becomes more exact, the less are we able to entertain those theories which are generally offered in explanation of the repeated inundation and emergence of the continents.

CHAPTER VII

TERTIARY SEAS AND RECENT LIMESTONE FORMATIONS

Negative phase at the close of the Cretaceous period. The central Mediterranean of the Tertiary aera. The east coast of North America. The Tertiary region of Patagonia. Recent limestone formations. Summary.

1. *Negative phase at the close of the Cretaceous period.* Towards the end of the Cretaceous period events occurred similar to those which characterized the later ages of the Jurassic period. The sea was reduced in area. The prairie land of North America, from Canada down to Texas and Alabama, was laid dry, and the Laramie stage, formed of alternating brackish and fresh-water beds, corresponds to this period of the retreating strand. The mammalian fauna of the Tertiary aera had not yet made its appearance, but great reptiles were the most striking representatives of the terrestrial fauna, as in the Cretaceous period. During the same epoch the basin of the Amazon was abandoned by the sea: the brackish-water deposits of Pebas are the only traces so far known of the influence of the sea in post-Cretaceous times; they belong to the Eocene or Oligocene period (I, p. 512). Simultaneously the strand receded from north to south in England, the horsts of central Europe were abandoned by the sea; in Russia the shore receded to the south. Far and wide fresh land made its appearance.

When the negative phase, towards the end of the Jurassic period, had attained its maximum, the sea occupied the central Mediterranean, in other words the site of the younger folded ranges of western Eurasia; but outside this region, over an area extending up to its borders, as in the Jura for example, deposits of gypsum were first laid down, and then an alternation of fresh-water and marine beds which still bore a Jurassic facies.

Events followed much the same course towards the end of the Cretaceous period.

From Spain through the south of France, and particularly in Provence, we find, resting on the marine Cretaceous, fresh-water beds, which are followed in certain areas by a series with marine shells of Cretaceous type. This is Leymerie's *Garumnian stage.* It occupies the same position with regard to the Cretaceous system, as the Purbeck to the Jurassic.

The Garumnian stage has been studied in Catalonia by Vidal, by Mallada in Huesca, and by Leymerie, Matheron, and others in the south of France [1].

In the Jura we found it possible, notwithstanding the folding, to determine the outlines of the several lacustrine areas, which were formed at the close of the Jurassic and the beginning of the Cretaceous period, and similarly in the present instance, in spite of foldings and various subsequent dislocations, we are already in possession of data, thanks to the zeal of observers, which will enable us to ascertain the course of events during this phase, equally negative, which marks the transition from the Cretaceous to the Tertiary aera.

The lowest member, as in the Jurassic, is the most restricted in distribution. It consists of the lignitiferous fresh-water beds of *Fuveau*. These rest on the upper Cretaceous, which has already acquired a brackish water character: they occur only in the neighbourhood of Marseilles, extending westwards from this town as far as Martigues on the Étang de Berre, and for about the same distance to the north and east. They were probably deposited at the mouth of a river.

Above them come the fresh-water limestones of *Rognac*, distinguished by Lychnus and other fresh-water genera, which do not pass upwards into the beds above: the fauna, while purely fresh-water, is still thoroughly Cretaceous; land reptiles of Cretaceous age are also present. Over wide areas this division begins with a bed of bauxite (aluminium hydrate). It extends from the Var across the Bouches-du-Rhône, Vaucluse, Gard, Hérault, and Aude, and passes, in Ariège, into continually closer relations with the uppermost beds of the marine Cretaceous, which, in the Haute-Garonne, loses more and more its fresh-water intercalations [2]. The Rognac beds also occur in the north of Spain.

The third member consists in the east of layers of red clay, sandstone and pebble beds; to the west, on leaving the Rhone, the red clays increase in thickness; they are known as the '*argiles rutilantes*,' their brilliant colouring rendering them a conspicuous feature in the landscape; they extend over Hérault and Aude, and reappear with the same characters beyond the Pyrenees, still possessing a considerable thickness. They are very poor in fossils. In Provence the upper beds contain species of Physa, Lymnaea, and Planorbis, existing genera of pond and marsh snails; these continue into the succeeding beds. All Cretaceous types have now disappeared, among them the genus Pyrgulifera, which however still main-

[1] We need only mention here the succinct account by P. Matheron, Note sur les dépôts crétacés lacustres et d'eau saumâtre du Midi de la France; Bull. Soc. géol. de Fr., 1875–1876, 3e sér., IV, pp. 415–428.

[2] Croisiers de Lacvivier, Études géologiques sur le département de l'Ariège; Ann. sci. géol., 1884, XV, pp. 1–293, in particular p. 250.

tains its existence in lake Tanganyika. Above the clays follows first fresh-water limestone, with Physa, and then the marine Eocene.

It is thus the red clays which mark the division between the faunas. At their base the rich Cretaceous fauna of Rognac has disappeared, and from this time onwards the younger forms prevail. Matheron has brought this out in clear relief, and Roule, in his admirable description of the exposures in Provence, has placed the limit between Cretaceous and Tertiary at the base of these clays[1].

The same interruption of the marine series between the Cretaceous and Eocene is repeated in the region north and east of the Adriatic; Stache's investigations show that from Carinthia, through Istria, the islands of the Quarnero and a great part of Dalmatia, a varied group of intercalated brackish or fresh-water beds appears on the horizon. Near Sebenico the fresh-water limestone rests on an eroded surface of Cretaceous limestone. A pre-Tertiary red earth also takes part in these formations. The whole group of beds has been named by Stache the *Liburnian stage*, and correlated, at least in its lower part, with the Garumnian stage[2].

Thus at the close of the Cretaceous period the sea had again become extremely restricted. We now reach the first great stage of the marine Tertiary deposits. As we approach nearer to existing times the number of recorded observations increases, but at the same time the immense variety of facts becomes almost overwhelming, and description correspondingly difficult, since so much has to be condensed. To give in a few pages a fairly adequate account of the subject I must refrain almost completely from citing the sources of my information, and I must restrict myself to discussing the Tertiary and more recent marine deposits in three regions only.

The first of these is that which we have already alluded to as the central Mediterranean; the second is that of the west Atlantic coast from lat. 43° N. to the valley of the Orinoco; the third is formed by the Patagonian plains from Paraná to Tierra del Fuego.

With regard to Australia, especially the Bunda plateau, and the absence of Tertiary deposits on the east coast, I must refer to what has been said already (II, pp. 152, 162). The Tertiary deposits of the Pacific coast are unfortunately still little known. The Téjon group of California, which has recently been assigned to the Eocene, contains Ammonites, and differs in several respects from the European and the eastern American types. The same is true of the deposits of the island of Quiriquina, in Chili, which are

[1] L. Roule, Recherches sur le terrain fluvio-lacustre inférieur de la Provence; Ann. sci. géol., 1885, XVIII, in particular p. 129.

[2] G. Stache, Die liburnische Stufe, Verh. k. k. geol. Reichs., 1880, pp. 195–209; by the same, Ueber das Alter von bohnerzführenden Ablagerungen am 'Monte Promina' in Dalmatien, op. cit., 1886, pp. 385–387 et passim.

referred by some authors to the Cretaceous, by others to the Tertiary[1]. Folded Tertiary beds occur in the coastal chains of California, but their exact age has yet to be determined.

2. *The central Mediterranean of the Tertiary aera.* By the region of the central Mediterranean we understand, according to Neumayr's definition, a broad zone embracing the Betic cordillera, the whole Alpine system, and the larger part of the great ranges of Asia; from the Trias upwards it is distinguished by an uninterrupted series of marine sediments. When towards the end of the Jurassic, a negative phase set in over a considerable part of Europe, and the Purbeck and Wealden beds were deposited, this region still remained covered by the sea. The same was the case when the negative phase, which occurred at the limit between the Cretaceous and Tertiary, made itself felt. In the central Mediterranean region marine Cretaceous beds are covered by marine Tertiary beds, and both have subsequently been folded. But this continuity is not confined to great folded ranges; Zittel has shown that the marine Eocene beds of the Libyan desert rest directly upon the marine Cretaceous[2]. The Garumnian stage in Spain and the south of France, as well as the Liburnian stage in the region of the Adriatic, only represent marginal deposits of this sea, which doubtless was very much restricted.

The strand having sunk to its lowest level now began to ascend; through many oscillations the *Eocene sea* extended itself over the basin of Paris and a part of Belgium into the south-east of England. Strange and remarkable faunas appear and disappear, like those of the sands of Bracheux and the limestone of Mons, until finally the typical beds of the French Eocene, the Sables inférieurs and the Calcaire grossier of the Paris basin, were laid down. It is also evident that the Eocene sea, extending from the Atlantic, invaded the valley of the lower Loire. At the same time its sediments were spread out from the Carpathians and the Crimea over a large part of south Russia.

From the Betic cordillera the Eocene sea extended to north Africa; it embraced a large part of the eastern Sahara, then Syria, Arabia and Persia. From the great ranges of India it spread over Cutch and Guzerat, and over the plateau of Shillong.

Its sediments occur everywhere in the folded mountain chains, proceeding from the west through the Alps and Carpathians, the Apennines, and through the Crimea to the Himálaya: between the inner chains of the Himálaya a band of marine lower Tertiary has been traced for a

[1] C. A. White, The Chico-Téjon Series, Bull. U.S. Geol. Surv. Territories, 1885, No. 15, pp. 11–17; R. A. Philippi, Ueber die Versteinerungen der Tertiärformation Chiles, Zeitschr. gesammt. Nat., 1878, 3. Folge, III, pp. 674–684; near Quiriquina Plesiosaurus, Baculites, Trigonia occur in these beds.

[2] K. Zittel, Beiträge zur Geologie und Paläontologie der Libyschen Wüste, 4to, Cassel, 1883, p. xc.

distance of 300 kilometers, and it rises above Leh to a height of 21,000 feet (I, p. 438). The further continuation of these sediments in the great ranges of Thibet is not known, but Eocene deposits are seen again in Luzon. From the plateau of Shillong they extend into the folds of Burmah. The older Tertiary beds of the Malay arc from Sumatra to Borneo are likewise of marine origin: there is much difference of opinion as to their precise age. Some traces of Eocene have been said to occur in Madagascar also, but this statement has not yet received confirmation.

Notwithstanding the fragmentary state of our knowledge it is evident that sediments of the Eocene sea extend over the south of Eurasia in folded ranges, and that outside these ranges outposts of flat-lying deposits occur; in the north, as far as England and over the south of Russia; in the south, from the Sahara across Arabia, Cutch, Guzerat, and to the Brahmaputra. In breadth, this sedimentary zone, interrupted by islands, extends from London to Khartoum, and from Kiev to the Indian Ocean.

Notwithstanding its wide extent, the sediments of this sea are nowhere seen to overstep the limits of the Cretaceous area. In Europe its distribution is more restricted than that of the Chalk; in the whole of the south from the Sahara to Guzerat its sediments terminate in an escarpment, or, as in Arabia, in steep cliffs, or again, as in Shillong, by a flexure; they are everywhere superposed normally and conformably on the Cretaceous, and their southern shore is unknown.

In the west of Europe, where more detailed observations are at our disposal, a negative phase may again be recognized. The south of England was laid dry, and the Hempstead series was deposited in fresh water. The valley of the Seine was also abandoned by the sea, and the *gypsum of Montmartre* was deposited; beds of gypsum belonging to this period extend into Provence and into the neighbourhood of Mühlhausen in Alsace. Over northern Germany, which was not covered by the sea, a great formation of brown coal accumulated. This negative phase marks the boundary between the Eocene and Oligocene.

Once more Europe experienced a positive movement of the strand, and the *Oligocene sea* made its appearance. The beds of Castel Gomberto in the southern Alps, distinguished by a rich marine fauna and in particular by numerous corals, are known in many localities as far as Suez, as well as in Armenia. They extend into the south of France, overlie the freshwater beds and gypsum of the preceding negative phase, are exposed at Bordeaux, then at Rennes, and, as the sands of Fontainebleau, enter the basin of Paris, where they extend to the south somewhat beyond the boundary of the marine Eocene: they are represented in England only by brackish-water deposits; finally we meet with them as the marine sands of Weinheim in the Rhine valley near Mainz, and even above this city. These marine sands are covered by blue clay, the septarian clay, or

the Rupelian clay of Dumont. Opinions differ as to whether the marine sands entered the Rhine valley from the north or the south, but the northern origin of the superimposed septarian clay is indisputable [1]. The corals of Castel Gomberto are rare near Bordeaux (Gaas); in the Paris basin and at Mainz they have as good as disappeared, but the molluscan fauna is still that of a warm temperate climate. In the clay, on the other hand, species of boreal type predominate; this marine clay extends far over north Germany, through Berlin to Stettin and Königsberg; it is the same as that already mentioned as extending, according to Karpinsky, over the Russian plain, and on the east side of the Urals as far as lat. 58° N. (I, p. 322). About this time, therefore, the sea advanced from the north over the region of the Obi, then south of the Ural to Europe, and extended over Germany to Belgium.

Thus the course of the ancient marine transgressions over the Russian Platform has been as follows: from the south in the Callovian, from the north during the Volga stage, from the south in the Cenomanian, and from the north in the Oligocene period.

The shores receded once again. The *Aquitanian* lignite measures and the lower fresh-water molasse of Switzerland were deposited in central Europe. The succeeding positive phase, however, again falls within the range of those events, which have already been discussed in our sketch of the history of the Mediterranean.

The deposits of the *first Mediterranean stage* extend from the Azores and Madeira through the south of Europe, across Asia Minor and Armenia to Persia. In his latest travels, Griesbach found Tertiary beds, which may be the continuation of this great zone, in Khorassan; they contain marine shells which he regards as Miocene, and form a belt on the southern border of the Aralo-Caspian area, passing through Badghis, Maimeni, and even to beyond Taschkugan. Even across the Oxus, near Kilif, north of Balk, this indefatigable investigator found inclined beds of limestone rising from the Turkmenen steppe, and containing Ostrea, Pecten, and Polyzoa: he assigns them to Abich's Salt formation [2].

From these facts we perceive what a vast extension the ancient central Mediterranean still possessed in the middle of the Tertiary aera, when a fauna was already in existence closely resembling that of the present Mediterranean. The shells collected in Persia show, however, that the communication with India, which was still open during the Eocene period, now no longer existed.

[1] A. Andreae und W. Kilian, Briefwechsel über das Alter des Melanienkalkes und die Herkunft des Tertiärmeeres im Rheinthale; Mitth. Comm. geol. Landesuntersuch. von Elsass-Lothr., I, 1885, pp. 72–82.

[2] C. L. Griesbach, Field-notes from Afghanistán, Rec. Geol. Surv. India, 1886, XIX, p. 257; and by the same, Field-notes No. 5 to accompany a geological Sketch-map of Afghanistán and North-Eastern Khorassan, op. cit., 1887, XX, p. 199.

In Europe the northern shore ran up the Rhone valley, included a part of the Jura, and proceeded from the south margin of the Black forest to that of the Bohemian mass, and along the eastern side of the Manhart and the Sudetes to Silesia.

In the East over a vast area evaporation next set in.

This was the time of the *Schlier*, the deposit of an expiring sea. The salt beds of the Carpathians were then formed, and probably at the same time the great salt beds of Persia and Turkestan. Communication with the Rhone valley, across the existing Jura, had by this time ceased.

The blue marl of the Schlier is covered here and there by fresh-water deposits: tectonic changes occurred in central Europe: then came the *second Mediterranean stage*. By this time the greater part of the East appears to have been abandoned by the Mediterranean, at all events its asserted presence in Persia requires confirmation. To the north of the Crimea it still persisted, even as far north as the valley of the Manytsh, and has left behind some scattered deposits. In lower Austria and Hungary it entered freshly subsided areas of great size lying in the midst of the mountains, but Bavaria and upper Austria were no longer submerged by it.

A negative phase next followed, and isolated the *Sarmatian region*; the whole valley of the Danube, Galicia, the south of Russia, and the last remains of the Aralo-Caspian area were now abandoned by the sea. The Mediterranean was then restricted by another negative movement to a space even much smaller than that it at present occupies. Its eastern boundary probably lay near Corsica and Sardinia. At the beginning of this period *erosion* of the valleys occurred, as in the Rhone valley, some parts of western Hungary, and doubtless elsewhere: later on great inland seas existed, in which the Cardium beds of the *Pontic stage* were deposited; but the arrival of marine fishes, which ascended the rivers to spawn in the lakes, suggests that the negative period had already passed its climax, which corresponds in fact with the erosion of the pre-Pontic valleys. Up to the present we know of no true marine deposits of this period in the Mediterranean region, and thus Neumayr was justified in supposing that the *strand-line at this time was probably situated lower than at present* (I, p. 335).

A gap occurs in the Mediterranean series at this point; it marks the culmination of the negative movement, and it is at precisely this horizon that the limit is usually drawn on palaeontological grounds between the Miocene and Pliocene.

It is true that a positive phase again followed, but the sea of the third Mediterranean stage was far from attaining its former extent; its area was even much more restricted than at present, although the strand stood somewhat higher, since the subsidences in the region of the Adriatic, on the

Syrian coast, and in the Aegean, had not yet occurred. Next came the fourth Mediterranean stage, and the temporary northern immigration; this time, however, not from Siberia towards central Europe, as in the Oligocene period, but from the Atlantic Ocean. Local subsidences followed; the Pontus was annexed, and the present state of things established.

If we disregard the tectonic incidents, that which we observe is an alternation of positive and negative phases of different value; in each succeeding alternation the positive phase had less and less effect in extending the confines of the sea, or its area, as compared with the preceding positive phase, was reduced; until the negative maximum supervened in the period of erosion which preceded the Pontic lakes.

This gradual reduction was interrupted by a temporary transgression of the boreal sea in the Oligocene period.

The gain due to the slightly higher level of the existing strand, and to the addition of insunken areas, was by no means sufficient to balance the loss resulting from the decrease in amplitude of the positive movement, and thus the existing Mediterranean has come to represent the remains of an Ocean, which even at the commencement of the Tertiary aera still extended over central Asia.

An excellent idea of the way in which these phases succeeded each other may be obtained from Iwanow's map of the government of Stavropol. North of Pjatigovsk there rises a boss of quartz porphyry, surrounded by sandstone belonging to some early stage of the Tertiary; the second Mediterranean stage follows on the north, extending from Giorgiensk to beyond Stavropol; it is horizontally stratified and covers a considerable area; towards the north, i. e. towards the Manytsh, it is followed in its turn by the Sarmatian stage, also flat; this lies in a synclinal, and beyond the Manytsh the other flank of the synclinal makes its appearance: then follows within this synclinal of Sarmatian, a second, of Pontic beds; in this lies a third of Aralo-Caspian deposits, and in this flows the river Manytsh [1].

3. *The east coast of North America.* With regard to this region a number of facts of general importance have already been discussed (I, p. 281): a detailed description has been given of the stratified succession in Antigua (II, p. 135), so that we shall be able to treat with greater brevity the relations of the Tertiary beds on the west coast of the Atlantic with those of Europe: the facts bearing on this subject are mostly taken from Heilprin's latest works [2].

[1] Iwanow, Geologische Karte des Stawropol'schen Guberniums; Gornoi Journ., 1887, No. 7.

[2] A. Heilprin, Contribution to the Tertiary Geology and Palaeontology of the United States, 4to, Philadelphia, 1884, map; for the middle Tertiary beds of North Jersey, by the same, Proc. Acad. Nat. Sci. Phil., 1886, p. 351; further, by the same, Explorations on the West Coast of Florida and in the Okeechobee Wilderness; Wagner, Free Inst. Sci.

The gradual retreat of the strand is much less clearly expressed on the Atlantic coast of Europe than on the Mediterranean, because its outline is broken by rias coasts and is in general much more diversified; on the Guadalquivir, in Portugal, and on the Gironde, however, the retreat may be readily recognized. The American coast of the Ocean possesses a simpler structure. On the island of Martha's Vineyard (lat. 41° 20′ N.) a zone of marine Tertiary strata occurs, which rests regularly against the continent and borders the Ocean, proceeding through the peninsula of Florida and the Antilles to the Orinoco, that is through more than 33 degrees of latitude. These beds rest conformably on the upper Chalk for great distances, but are separated from it in the south by an 'eo-lignite' stage, and they are so disposed that successively younger members appear as we approach the sea. From this we may draw two conclusions: first, that this has been a littoral region since the Cretaceous period, and next that the coast-line has progressively receded.

Yet each of these results requires some modification.

Although for 33 degrees of latitude the marine beds lie as they were deposited since the middle of the Cretaceous, yet, apart from the early Cretaceous fauna of Bogota and the Cretaceous corals of Jamaica, there is such a close correspondence of the Oligocene corals of Castel Gomberto near Vicenza and of the first Mediterranean stage near Turin with those of the homotaxial deposits in the Antilles, that to account for the distribution of these corals we are compelled to assume the existence of a series of islands or a continuous coast-line, which as late as the first Mediterranean stage extended through the tropical zone.

The strand no doubt receded progressively, yet it is none the less probable that here, as in Europe, the existing level is not the lowest which has been experienced. The facts are as follows:—

The Tertiary selvage runs parallel to the coast from New Jersey through both the Carolines and Georgia; in Georgia it is nearly 260 kilometers in breadth, and its boundary bends in south Alabama gradually to the north, extends beyond the mouth of the Ohio into the Mississippi, and from there crosses the Rio Grande above Laredo to the south-west. All the other members, including the Orbitoides limestone, follow the north coast of the gulf of Mexico; there they are covered by the deposits of a great inland sea, the Grand Gulf series, which is absent on the Atlantic coast (I, Fig. 37, p. 284). At the same time, however, the Oligocene and Miocene, consequently the younger members of the Tertiary zone, proceed to the south through Florida towards the Antilles. Thus Florida is, as it were, one-sided, since the supposed equivalents of the European Miocene occur only along the Atlantic coast.

Phil., 8vo, Philadelphia, 1887; W. H. Dall, Notes on the Geology of Florida, Am. Journ. Sci., 1887, XXXIV, pp. 161–170.

But Heilprin has shown, in confirmation of Conrad's statements[1], that while these representatives of the Miocene are present all along the coast-line, from the north downwards, yet they are immediately followed by beds containing a much younger fauna, very similar to that now existing, and described as post-Pliocene, and further that as far south as Florida no one has yet succeeded in discovering an equivalent of the European Pliocene.

In the gulf of Mexico, about the mouth of the Mississippi, the very young, certainly post-Pliocene beds of the Port Hudson group, rest directly on the limnic beds of the Great Gulf series (lat. 29°–31° N.). In south Florida, on the other hand, new members make their appearance. On the river Caloosahatchie (lat. 26° 30′–26° 40′ N.) the *Florida stage*, rich in mollusca, appears, which Heilprin is inclined to compare with the European Pliocene. The existing sediments appear as the direct continuation of the very flatly bedded sediments of the preceding period, and the gradual retreat of the strand finds expression in the fact that the older beds were deposited in deeper water, the younger in less deep. Dall, it is true, believes that here also he has found traces of oscillations.

The younger zones of Florida are continued into the outer zone of the Antilles.

In this important region of North America, where many questions still await solution, investigation will certainly bring to light much that is new: at present we may record the fact that in the region of the European Mediterranean a regular negative maximum occurred between the Miocene and Pliocene, from which we may conclude that the strand-line in this region then stood at a lower level than at present, and that on the other side of the Ocean, in about the same latitude and still a little further to the south, a gap occurs between the supposed upper Pliocene and the post-Pliocene, which overlies it: further to the south, however, in Florida, this gap has not been shown to exist.

4. *The Tertiary land of Patagonia.* The Tertiary beds which advance, south of Paraná, through 20 degrees of latitude to the Atlantic coast, differ from those of North America in two respects: in the first place they include a series of terrestrial formations, with which occasional marine beds are intercalated; and next, these terrestrial deposits end against the sea-coast, in such a manner as to show that the mainland once extended much further to the east. In the north they proceed a long way up the Paraná, and towards the west nearly reach the eastern slopes of the Andes. The resemblance of the basin of the Paraná to that of the Mississippi is very striking.

These beds form the most extensive Tertiary land in the world: their wide distribution in a north and south direction affords an excellent

[1] T. A. Conrad, Catalogue of the Miocene Shells of the Atlantic Slope; Proc. Acad. Nat. Sci. Phil., 1862, p. 559.

opportunity for probing the questions with which we are now occupied. The latitude of the strait of Magellan corresponds very nearly with that of Cambridge and Birmingham, and the latitude of Paraná closely enough with that of Alexandria: hence we may hope to obtain some information as to the nature of the events which happened in the southern hemisphere contemporaneously with those in corresponding latitudes of Europe.

Our knowledge of this subject is chiefly due to d'Orbigny and Darwin, Burmeister, Ameghino, and Doering, particularly to Doering, whose account I am now about to follow[1].

The Tertiary beds of Patagonia present no signs of dislocation. But if we trace along the coast the level of the marine intercalation, which is supposed to be Oligocene, we shall find that it rises and falls in a gently undulating curve from the mouth of the Paraná to south Patagonia: this is in correspondence with the fact that one flat basin lies beneath the Pampas, another beneath south Patagonia, and that in some places the Oligocene beds dip beneath the sea. The undulations throughout this great distance are, however, so extraordinarily flat that we may perhaps regard them as representing merely an original inequality of the sea floor.

The Tertiary beds of Patagonia repose on the Cretaceous. In this case also the marine deposits are more recent as they lie nearer to the coast; here also great and exceedingly uniform oscillations have taken place, giving rise to an alternation of terrestrial and marine deposits; and here, once more, the diminishing amplitude of the positive phases conducts us to the existing state of things, while at the same time an inequality of great interest occurs in the movements.

Upon the Cretaceous formation, and not sharply defined from it, rests the unfossiliferous *Guaranitic stage*: it is overlaid by a thick group of red sandstone and sandy clay, with gypsum; this occupies wide areas in the west, towards the slopes of the Cordilleras (*Piso Pehuenche* with *Mesotherium Marshii*). To this stage we must perhaps refer the lignites of Punta Arenas. Next, for the first time since the Cretaceous period, a positive phase occurred. The deposits of this marine stage are exposed at many localities on the coast and in the interior: they everywhere contain the same mollusca, over their whole extent, from Paraná to Punta Arenas, where they rest on the lignites (*Piso Paranense* with *Ostrea Ferraresi*): they are correlated with the upper Eocene of Europe. The strand again receded, and beds of sandstone were laid down, with remains of plants and fresh-water mollusca, as well as mammals, among them genera closely allied to Palaeotherium and Anoplotherium of the gypsum of Montmartre (*Piso Mesoptamico* with *Megamys Patagoniensis*).

[1] Informe oficial de la Comision científica agregada al expedicion al Rio Negro bajo l'órden de General Don J. A. Roca, 4to, Buenos Aires, 1883, III, Geología, por el D. Doering, pp. 401–530.

Then for the second time the strand rose, but the marine deposits did not extend so far inland as in the preceding transgression: they probably correspond with the Oligocene (*Piso Patagonico* with *Ostrea Patagonia*). The most westerly point at which the first marine stage occurs is Lago San Martin, near the Cordillera (lat. 49°–50° S., west of long. 72° W.), while this second marine stage only attained, generally speaking, a half to one-third of the distance which intervenes between the sea and the Cordillera.

Then the strand retired for a long distance and for a very long period; several stages of continental deposits follow one another, uninterrupted by marine intercalations. Great quantities of trachytic detritus, which in the south occur in the upper part of the second marine stage, are continued into the lower part of the succeeding continental deposits. These begin with sandstone and marls: they contain the genus Anchitherium, indigenous in Europe during the lower Miocene (*Piso Araucano*). Then comes the alluvial sand of the western Pampas (*Piso Puelche*): *at the close of this stage Doering places the limit between the Miocene and Pliocene, which coincides with the greatest recession of the strand.* The continent then extended much further to the east than at present. We have now reached the Pampas formation, in the strict sense of the term; it consists of clay with numerous remains of terrestrial mammals, and is subdivided into three stages—*Piso Pampeano inferior* with *Typotherium, Protopithecus*; *Piso Eolitico*; and *Piso Pampeano lacustre.* It is supposed to represent the Pliocene.

A vast sheet of pebbles and conglomerate was now spread over the Patagonian plateau: it probably came from the Cordillera, and stands in some relation to the Glacial epoch. Erosion of the valleys then took place, and not till this period did the sea appear for the third time (*Piso querandino*). It did not, however, extend far beyond the coast, least of all in the north, and the fauna corresponds very closely with that of the present day. This recent post-glacial transgression is thus separated from the two earlier transgressions, which contain none but extinct species of mollusca, by a great hiatus, an interval wholly unrepresented by Miocene or Pliocene deposits.

Doering adds that to discover the missing members between the second and third transgressions, we should have to make borings off cape Corrientes beneath the sea.

In spite therefore of the great uncertainty as to the precise age of the beds, there is a remarkable concordance between the results obtained in three regions widely remote from each other by three able investigators, working independently. Neumayr of Vienna finds that at the beginning of the Pontic stage, which is generally recognized as the limit between the Miocene and Pliocene, the strand in the Mediterranean occupied a lower level than at present, and that in the Pontic period, or at the

beginning of the Pliocene, there is a gap in the series of marine beds. Heilprin of Philadelphia says that on the Atlantic coast of the United States the Pliocene is not represented, and that the Miocene beds are separated by a gap from the succeeding and much younger shell beds. Doering of Cordoba arrives at the result that on the coast of Patagonia the strand must have retreated far from its present position, that the land must have attained its greatest extension at the limit between Miocene and Pliocene, and that the Tertiary, probably Oligocene, marine beds are separated from the post-glacial shell beds by a great gap.

We will now return to the quer-Andinian shell beds. These are the recent deposits which were so clearly described by Darwin. Doering, who has traced the regular oscillations they record through 20 degrees of latitude, has no doubt that such movements could not have been caused by displacements of the solid land. A very remarkable peculiarity of the movement is *its increase towards the south.* In the bay of Plata the quer-Andinian shell beds occur at +20 to 30 meters; rising southwards they reach +100 meters in the extreme south, where they are surrounded by terraces at +300 to 400 metres. We shall revert to this fact later on.

5. *Recent Limestone Formations.* Formidable difficulties are connected with the question of the present deposition of limestone, and particularly with the mode of formation of those coral islands, so frequently ring-shaped, which rise from the great Ocean depths.

Darwin distinguished three different kinds of coral reefs: first, *fringing reefs,* which adhere closely to the land or a reef of rocks; next, *barrier reefs,* separated from the land by a deep channel; and finally ring-shaped *atolls,* surrounding a lagoon, within which no land is visible. He attempted to explain the transition from group to group by assuming *a gradual subsidence of the sea floor.* Dana also adopted this view, as the result of very extensive observations of his own. Whatever opinion we may form as to the subsidence theory of Darwin, it needs no proof to show that a rising of the sea in the torrid zone would meet the facts in precisely the same way as a subsidence of the sea floor. Both Darwin and Dana were well acquainted with a great number of apparently elevated coral islands, and they sought to distinguish between zones or regions of elevation and subsidence [1].

Wilkes, the leader of the American expedition, which Dana accompanied, expressed himself against Darwin's explanation, influenced apparently by having seen a number of elevated reefs, i.e. reefs laid dry by negative movement; and in 1855 J. C. Ross, who had lived for many years on Cocos island (Keeling atoll), the starting-point of Darwin's

[1] C. Darwin, The Structure and Distribution of Coral Reefs, 2nd ed., 8vo, 1874; J. D. Dana, Corals and Coral Islands, Am. Journ. sci., 1885, 3rd ser., XXX, pp. 89–105 and 169–191.

observations, opposed his theory even more strongly. In the first place, Ross maintained that Darwin's statements regarding recent subsidence on Cocos island were incorrect; and subsequently H. Forbes also asserted that in this case Darwin had been mistaken. The paper published by Ross on this subject is marred by much obscurity of thought as regards volcanic activity, and by other defects, which may be lightly passed over as the result of a lengthy residence on remote islands. On the other hand, it contains some valuable observations; Ross remarked that all the elevated coral islands of the Pacific rise to about the same level, and that it appears as if the whole surface of the Ocean had suddenly sunk in consequence of the subsidence of one or several parts of the sea floor towards the centre of the earth. He further points out that Darwin represents elevation and subsidence as distributed in long separate zones, whereas elevated islands (reefs laid dry) and, according to Darwin's views, sunken islands (atolls) occur on the same line, close beside each other, and in between each other. He concludes that the distribution of coral reefs is determined by marine currents, which bring them nourishment [1].

Finally, Semper, Rein, and Murray have of late years questioned the validity of Darwin's subsidence theory, because, in the opinion of these observers, the growth of the corals is always confined to the outside of the reef, where food is to be found; while by the death of the interior part ring-shaped forms are produced, for which no subsidence of the ground is required [2].

This question, which has such an important bearing on the statics of the sea, is discussed now because in various parts of the world limestones of recent formation occur in association with others, which are of late Tertiary age, and it is sometimes difficult to discover a strict limit between them. Examples of this association are far from rare: on Antigua the beds which reach the sea are Miocene, and it ought not to be difficult to distinguish them from the younger formations (II, p. 136, Fig. 15). The problem is more complicated in the case of the limestone of *Curaçoa, Aruba, and*

[1] J. C. Ross, Review of the Theory of Coral Formations set forth by C. Darwin, &c., Nat. Tijdschr. Ned. Ind. Ver. Batavia, 1855, VIII, pp. 1–43; H. Forbes, Notes on Keeling Island, Proc. Geogr. Soc., 1879, pp. 777 et seq.

[2] C. Semper, Die Riffe und das Leben im Meere, Zeitschr. wiss. Zool., 1863, XIII, pp. 563–569, printed in his Die Philippinen und ihre Bewohner, 8vo, Würzburg, 1869, pp. 100–109; by the same, Die natürlichen Existenzbedingungen der Thiere, 8vo, Leipzig, 1880, II, pp. 39–93 and 261; J. J. Rein, Beiträge zur physischen Geographie der Bermuda-Inseln, Ber. Senckenb. naturf. Ges. Frankf. am Main, 1869–1870, pp. 140–158; by the same, Die Bermudas-Inseln und ihre Korallenriffe, nebst einem Nachtrage gegen die Darwin'sche Senkungstheorie, Verh. I. deutsch. Geogr.-Tages zu Berlin, 8vo, 1882, pp. 29–46; J. Murray, On the Structure and Origin of Coral Reefs and Islands, Proc. Roy. Soc. Edinb., 1879–1880, X, pp. 505–518.

Venezuela, which has been investigated by Lorié [1]. In *Florida* the complication is still greater. Species pass into new forms or become extinct; those corresponding with still existing species increase in number, and the marine fauna of the West Indies is itself, like that of the existing Mediterranean, an assemblage of elements of different age and origin.

For the purpose of a general survey it will be convenient first to refer to some observations in the Atlantic region,—Florida, the West Indies, and the Bermudas in particular, and next to discuss the chief structural features of the widely distributed coral reefs of the Pacific.

The peninsula of *Florida* in the north and north-west is formed, as we have several times observed, of the middle Tertiary Orbitoides limestone, which towards the Ocean rests against a zone of Miocene coming from the north; to the south younger beds of limestone appear, till in the Everglades the surface of the plateau stands nearly level with the existing surface of the sea. Still further to the south the plateau forms the ragged shore line of the bay of Florida; the shallow waters of the bay, only a few fathoms deep, cover a broad horizontal surface of calcareous mud, a region where material is at present accumulating for the formation of a new limestone plateau, similar to that of the existing peninsula.

The bay of Florida, and Key Biscayne bay, its continuation to the north, are bounded on the Ocean side by a long series of low islands, the Keys, which run in a regular curve from the southern point of Virginia Key in the north, first to the south, then in an arc to the west up to the bank outside the Marquesas, through which it proceeds and reaches the Tortugas. As early as 1863 E. B. Hunt showed that this curve is produced by the counter current coming from the north, which flows between the land and the Gulf stream. The counter current limits the zone of coral growth, since it drifts sediment from the north, and brings food to the corals. Alexander Agassiz has given a highly instructive account of the facts, and has shown how storm and waves attack the organic structures, break off fragments, and grind them to a white impalpable powder, which is driven during the storms along the Keys and through the gaps into the broad quiet waters of Florida bay, where it is spread out by the play of the tides and accumulates on the sea floor as a fine calcareous silt. On the western side of Florida this accumulation of calcareous sediment also occurs and extends far to the north, covered above by a thin crust of corals. These are frequently killed by the stifling mud which finds its way into their calyces. It is not, Agassiz remarks, that the sea floor has risen to a height at which corals could settle on it, but that the sediments have accumulated up to this height. As to the Keys, the Tortugas, and above all the Marquesas, a more or less annular form, which marks them as true atolls,

[1] J. Lorié, Fossile Mollusken von Curaçao, Aruba und der Küste von Venezuela; Samml. geol. Reichsmus. Leiden, 1887, 2. Ser., I, pp. 111–149, pl.

has been produced solely by the influence of the currents, which brings nutriment to the coral polyps [1].

Here then we have before us at once our first example of a limestone plateau now in process of formation, and an illustration of the objections which have been raised to the theory of the origin of atolls by subsidence of the sea floor.

Similar accumulations of calcareous mud and dead organic débris are known over large areas in other parts of the West Indian region, off Cuba for example, and particularly along the Tertiary plateau of Yucatan. *Alacran reef* (Scorpion rock) is a horseshoe-shaped atoll crowning recent calcareous sediments; it has doubtless arisen, like the Tortugas and Marquesas, without any appreciable displacement of the strand.

In the West Indies signs of negative movement may be seen in many places. I do not allude to the limestone beds occurring at some considerable altitude, the highest of which are found in Cuba and Jamaica, for although they have been regarded as reefs of comparatively recent date, their age is wholly unknown, and they may even belong to the Cretaceous period [2]; independent of these there are many indications of movement, even close to the existing strand. Over the whole of the east coast of Florida, nearly as far as the commencement of the Keys, lies a shelly breccia, the 'Coquina of St. Augustine,' which engirdles the coast and is regarded as marking a negative movement of 10 to 20 feet. This deposit appears in many islands of the Antilles: a well-known example is the Basse Terre of Guadeloupe, which is surrounded by a recent coral reef. Yet it must not be overlooked that the height above the sea of this last mark or last level surface does not afford a trustworthy measure of the movements which have taken place during the existing phase (II, p. 25).

Among the regions now laid dry in consequence of these movements we must include the island of *Sombrero*, lying out to sea in lat. 18° 36′ N. between the Virgin isles and the lesser Antilles.

Sombrero, according to Sawkins, is a little more than a nautical mile in length, and its greatest breadth is scarcely a third of its length. The whole coast is bounded by a perpendicular or overhanging cliff, 25 to 40 feet high, with 12 to 14 fathoms of water outside. The greatest difference of level in the interior amounts to 10 feet: the surface is scored with grykes or fissures of erosion. 'A more desolate or inhospitable spot can hardly be found in the actual world or in the realms of the imagination.'

[1] A. Agassiz, The Tortugas and Florida Reefs; Mem. Am. Acad. Sci., Centennial Volume, Cambridge, 1885, XI, pp. 107–133, maps.

[2] W. A. Crosby, On the elevated Reefs of Cuba; Proc. Boston Soc. Nat. Hist., 1882–1883, XXII, pp. 124–130. The terraces of limestone lie at heights of 30 feet, 200–250 feet, and 500 feet; even the limestone of the Yunque at a height of 1,800 feet, which is entirely different, is considered by Crosby to form part of the same group.

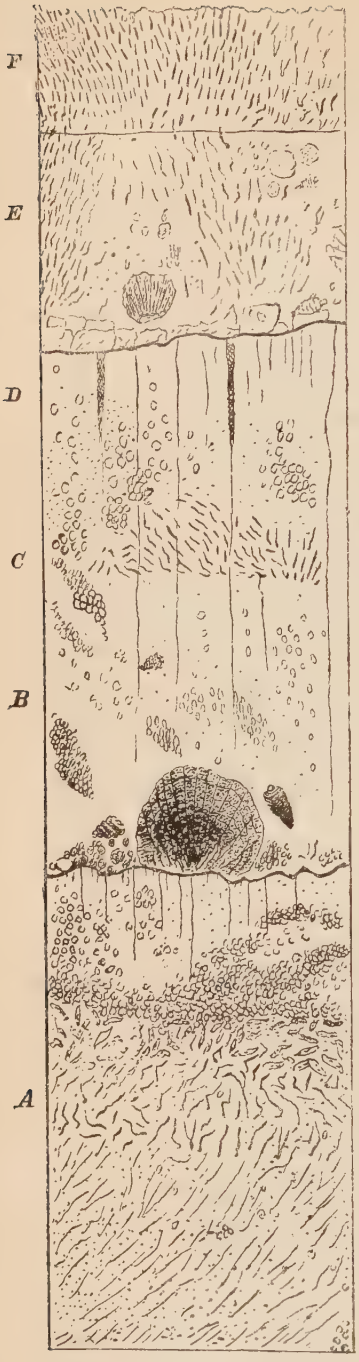


FIG. 29. *Limestone beds in Sombrero* (after A. Julien).

The whole island is formed of limestone; the mollusca enclosed in the limestone belong to the existing fauna, with the exception of a very common Bulla, which appears to be *Bulla granosa* of the middle Tertiary of the West Indies. Dykes of phosphates occur in the limestone, evidently derived from vanished beds of guano. They have been a source of attraction to this barren island since 1856; a description of them has been given by Alexis A. Julien[1].

Six beds of limestone are to be distinguished, resting horizontally one on the other; we will indicate them from the sea-level upwards by the letters *A* to *F*. On the face of the cliffs, however, only two bedding-planes, as a rule, are at all conspicuous: they are distinguished by partings of a different nature which occur between *A* and *B* and between *D* and *E*. A further distinction is afforded by the colour; *D* is decidedly grey, and thus stands out in marked contrast to the other beds, which are pure white. Beds of guano have been formed, according to Julien, at three different epochs at least: each of these beds, however, was subsequently removed by the sea, leaving some remains in the clefts of the limestone.

[1] Sawkins, Report on Jamaica, I, p. 261; Cleve, Geology of the West Indian Isles, p. 21; A. A. Julien, On the Geology of the Key of Sombrero, Ann. Lyc. Nat. Hist. N. York, 1867, VIII, pp. 251–278, pl.

Julien concludes from this, as well as from the character of the limestone beds, that the island had been repeatedly submerged and again laid dry. He has attempted to represent the oscillations graphically by a curve, and even for the trifling number of beds here visible, was obliged to assume eight elevations and nine subsidences of the ground.

The resemblance of these beds to those of the eastern Alps is evident. Whether each single bed does indeed correspond to an oscillation or not, there can be no doubt that we have before us here formations which bear a striking likeness to the stratified limestones of earlier epochs.

The limestone beds which rise within the encircling coral-reefs in the West Indies are tunnelled by many large caves. In the Bahamas, where a series of ancient strand-lines may be recognized, such caves occur in many places. Sharples has described those of the *Caicos islands* in the neighbourhood of the Turk islands: the floor is covered with red earth, gypsum, and guano[1]. It seems to me scarcely possible to doubt that these terraced limestones, excavated by caverns, are older than the living reef around them. Their great age is confirmed by the fact that Pomel and Cope have found the remains of extinct species of terrestrial animals in similar caves in the little island of *Anguilla*, and from this the great age of the negative movement may be inferred.

We conclude then that small annular atolls without deep lagoons, such as the Tortugas and Alacran, may be formed without any appreciable positive movement of the strand. The existing Keys of Florida must have been built up since the last negative movement. If a positive movement is now in progress it is so trifling that the sediment is able to keep pace with it. The negative movements and the caves with remains of extinct terrestrial mammals date from a more remote period. It is not improbable that the separation of the limestone into beds is due to minor oscillations; Sombrero seems to suggest this, but in the bay of Florida a change in the nature of the sediment might easily be brought about merely by the closing or enlargement of the openings between the Keys, by increased evaporation, or in other ways, without oscillation of the strand.

In the *Bermudas* we are afforded the rare opportunity of observing the submarine structure of a group of calcareous islands. They have been described by Nelson, Jones, Rein, the members of the *Challenger* expedition, and Rice[2]. A recent outer reef clings close to the south-east side of the

[1] S. P. Sharples, Turks Island and the Guano Caves of the Caicos Islands; Proc. Boston Soc. Nat. Hist., 1884, XXII, pp. 242–252.

[2] R. J. Nelson, On the Geology of the Bermudas, Trans. Geol. Soc., 2nd ser., V, p. 103; J. J. Rein, Beiträge zur physischen Geographie der Bermuda-Inseln, Ber. Senckenb. naturf. Ges. Frankf. am Main, 1869–1870, pp. 140–158; J. M. Jones, Recent Observations in the Bermudas, Nature, Aug. 1, 1872, p. 262; W. Thomson, The Atlantic, 8vo, London, 1877, I, pp. 290–357; W. N. Rice, The Geology of Bermuda, in Jones and Goode,

higher islands, but recedes from them on the south-west, as well as on the north, for a considerable distance, to form a broad oval ring, which thus encloses all the higher islands and an extensive lagoon. The islands attain a height of 250 feet, and are formed above the sea-level of drift rock, that is, of organic débris which has been piled up to this height by storms, and then either loosely cemented together, or converted into dense and compact limestone, by the rain. Red earth covers the islands, penetrates into the fissures of the white limestone, and forms the soil for vegetable growth. There are caves in the limestone with stalactites hanging from the roof. In some places indications of oscillations are to be seen; at Stocks point Rice describes a bed of beach conglomerate, formed of masses of drift rock, with large sea shells and compact lumps of red earth. This conglomerate occurs as an intercalation in the drift rock, which contains land shells.

At the mouth of Hamilton harbour submarine mining was commenced in 1870, and, according to Jones, a cave with stalactites and red earth was encountered at a depth of 6 fathoms. Excavations were continued later on a larger scale, with a view to the construction of docks. At a depth of −25 feet, a calcareous mud was met with, 5 feet thick; beneath this loosely cemented coral sand, with fragments of Diploporia and shells; then followed, at a depth of −45 feet, a layer of peat moss or rather old vegetable soil, with upright stumps of trees, land shells, and bones of birds. This lay on ancient limestone.

We have here definite proof of positive movement: nevertheless Rice concludes, with a high degree of probability, that no appreciable change has occurred since 1609. If the movement is still in progress it must be very slow. Rice bases this result on a number of ancient observations collected by him.

In passing to the *Pacific region* we may mention first that here, at least in the regions which border it on the west, there is no lack of evidence in proof of continuity between the very recent limestone formations and those of an earlier date.

Tertiary deposits play a large part in the formation of the archipelago west of New Guinea, and recent limestone immediately follows patches of Tertiary. The *Aaru* archipelago, according to Riedel, includes twelve large and eighty-three smaller islands; all form part of a single limestone plateau. Five very narrow channels of the sea, not broader than fairly large rivers, separate the six principal islands, which form together a plateau 180 kilometers long, with a slightly undulating surface, covered with marshes, in which brackish-water mollusca live. The south-east part of the island, which is the highest, and rises to 50 meters, is formed of late Tertiary beds (II, p. 166).

Contribution to the Natural History of the Bermudas, I (Bull. U.S. Nat. Mus., No. 25), 8vo, Washington, 1884, pp. 1–32.

The *Bunda plateau* of South Australia shows to what dimensions an exposed platform of Tertiary limestone may attain.

Tertiary fossils have been recorded even from *Viti Levu*, Fiji (II, p. 164).

In the region of the Pacific coral reefs, as in the West Indies, there are numerous traces of negative movement. Tabular limestone masses with a horizontal surface rise out of the rings of living reef; sometimes they are terraced in steps, sometimes ruled along their steep cliffs with horizontal strand-lines. Caves with stalactites run through them, sometimes for miles; and red earth occurs on their upper surface. Masses of limestone such as these are met with here and there as far to the east as Henderson (Elizabeth) island, beyond the Paumotu islands; this, according to Beechey, is 80 feet high, with steep cliffs composed of limestone which breaks with a conchoidal fracture like a Mesozoic limestone[1]. Nowhere, however, does the height of the plateau appear to exceed 100 meters. We do not know what part blown sand or drift rock plays in the structure.

In the south part of the *Pelew* islands the negative signs become so marked that Semper was inclined to attribute the origin of the group, not to subsidence as Darwin did, but to an elevation of the sea floor. The limestone cliffs here attain a height of 250 feet, and end above in a perfectly horizontal line; towards the east they are 80 feet high, and again horizontal at the summit[2].

On the slopes of the islands in *Bougainville straits*, in the Solomon group, regular terraces occur, which Guppy regards as so many elevated barrier reefs[3].

One of the most striking examples is afforded by the *Loyalty group*, which borders New Caledonia, like a second line of coast. The islands form a long series. The first is *Astrolabe*, which is just awash. The second is *Uvea*, a circular island formed of coral limestone, rising in a single step to a height of 15–18 meters. In the centre lies a lagoon with a very level floor and a maximum depth of 18 meters; the island is quite horizontal, and terminates against the sea in an overhanging cornice.

The third island is *Lifu*; this has no interior lagoon; it is a plateau, rising in three horizontal stages to a height of 90 meters. For thirty nautical miles, from one end to the other, each stage maintains precisely the same level. Great caves are to be seen. The sides of the plateau sink to unfathomed depths, as is the case with all these islands. So Chambeyron described it; Clarke, who gave an account of Lifu in 1847,

[1] Captain F. W. Beechey, Narration of a Voyage to the Pacific and Beerings Straits, 4to, London, 1831, I, pp. 55–58 and 187.

[2] Semper, Existenzbedingungen, II, p. 76.

[3] H. B. Guppy, Suggestions as to the Mode of Formation of Barrier Reefs in Bougainville Straits, Solomon Group; Proc. Linn. Soc. N.S.W., 1884, IX, Sydney, 1885, pp. 949–959, pl.

found evidence of two elevations, one of 80, the other of 170 feet, or together of 250 feet. Balansa mentions the red earth, without which vegetation could not exist, and recognized four stages, of which the third runs right round the island. There are wells in the limestone, 41 meters deep; it shows no stratification.

The fourth island is *Maré*; it presents, according to Chambeyron, five stages, all horizontal and still more clearly defined than in Lifu; the upper-

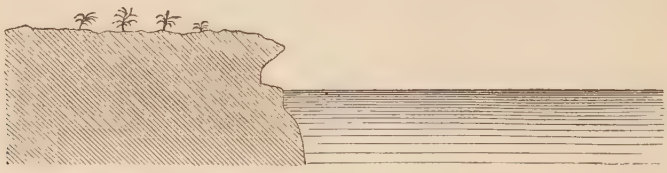


Fig. 30. *Uvea, Loyalty Group* (after Chambeyron).

most plateau reaches a height of 90 to 100 meters. Between the second and third stage lies a broad plain. In the north-west of the island the plateau of the highest stage occurs; here a peak of volcanic rock protrudes.

Towards the north-west the Loyalty group ends in the *Petrie* reef, and to the south-east in the Durand reef and *Walpole* island, the last an isolated rock 95 meters high.

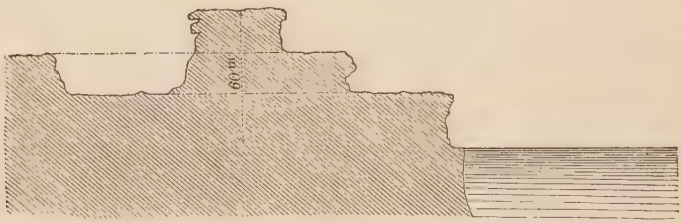


Fig. 31. *Lifu, Loyalty Group* (after Chambeyron).

It may be asserted that each of these islands, while maintaining its horizontality, has been raised spasmodically to these heights; Maré to 90 to 100 meters, Lifu, 90 meters, Uvea, 15 to 18 meters, and Astrolabe not at all. For my own part I cannot regard this as probable. I should prefer to suppose that to begin with there was a continuous limestone plateau, +90 to 100 meters in height, and at this time the sea-level stood at least 90 to 100 meters higher than at present. Of the highest part of this plateau one fragment has been preserved in Maré close to the volcanic peak, and another in Lifu; the lower stages mark a cessation of the negative movement or a phase of the positive recurrence, or perhaps merely the intercalation of a less resistant bed. The overhanging cornice of Uvea

shows how the breakers are engaged in their work of destruction to-day, as they have always been in the past [1].

Finally, mention may be made of the island of *Metia*, which lies north of Tahiti. According to Dana it is 250 feet high, and consists of coral limestone with great stalactitic caves; on its summit is a plain, similar to the beach platform of existing coral islands; isolated sea stacks show that a part of the limestone has been removed by the sea. Two horizontal lines run round the brow of the cliff; along these caves are frequent; the rock in consequence presents a stratified appearance, and is divided into three almost equal parts. It appears to me a fact of great interest that of the two specimens of the rock which Dana took from Metia, one contained 38·07 and the other only 5·29 *per cent.* of magnesium carbonate. Here dolomite and limestone have been deposited in the open sea, as in the Plattenkalk of the Alps. Dana regards Metia as the core of the deposits which filled up a once existing lagoon, and thinks that the carbonate of magnesia may have been precipitated in this lagoon as a consequence of evaporation [2].

Far more numerous than these comparatively elevated islands are those of inconsiderable height, particularly such as are bordered by an overhanging cornice, which rises no more than a few meters above the sea-level.

Attempts have been made to explain the inequality in height of these islands by an unequal elevation or subsidence of the various regions in which they occur. This is a view I cannot share. The existence of the limit of 100 meters, which is rather strictly maintained, is opposed to it, as well as the occurrence of repeated terraces or strand-lines.

These facts tend rather to show that all these limestone plateaux are the remains of older formations, certainly older than the living reefs of the present day; like the similar limestone plateaux of the Bahamas, which are also excavated by caves and covered by red earth; and probably all the negative movements to which they bear witness have affected uniformly the entire region of these coral islands, and belong to a more remote period. We do not know the age of these higher limestone plateaux. Dana has often expressed the opinion that the epoch of the Pacific coral reefs embraces the whole Quaternary, and perhaps a part of the Tertiary period. Consequently it is not to these plateaux that we should turn for an explanation of the existing state of things; this can only be obtained by a study of the living reefs.

[1] Captain Chambeyron, Note relative à la Nouvelle-Calédonie, Bull. Soc. géogr., 1875, 6e sér., IX, pp. 566-586; W. B. Clarke, On the Geology of the Isle of Lafû, Quart. Journ. Geol. Soc., 1847, III, pp. 61-64; B. Balansa, Nouvelle-Calédonie: les îles Loyalty, Bull. Soc. géogr., 1873, 6e sér., V, pp. 521-534; Grundemann, Peterm. Mitth., 1870, XVI, pp. 365-369. Chambeyron gives Lifu a height of 90 meters in the text, of 60 meters in the diagram; the first figure corresponds with that of other observers.

[2] Dana, Coral Islands, pp. 193, 357; Ribourt, Observations géologiques sur Tahiti et les îles basses de l'archipel des Paumotus, Bull. Soc. géogr., 1878, 6e sér., XVI, p. 35.

Darwin was well acquainted with the more active growth on the outer side of the reefs, and Dana even remarks that a coral reef is a limestone plateau with a living edge. Nevertheless it appears from recent observations that the influence of the currents, which bring nourishment, is much greater than Darwin and Dana supposed. They may of themselves give rise to annular reefs of no great size; this is shown by the little atolls of Florida, and we must probably refer to this cause the small atolls of *Mahlos Madhu* in the Maldives, which are grouped together into larger rings; Darwin has fully described them. The little goblet-shaped reefs of Serpulite limestone in the Bermudas belong to this class. But Alexander Agassiz himself has expressly admitted the difficulty of explaining lagoons of great depth, without conceding a change of level[1]. Semper, in a section through *Babelthaub*, the largest of the Pelew islands, has estimated the depth of the lagoon at 50–60 fathoms, and numerous soundings in lagoons have reached these figures. According to all observations so far made reef-building corals cannot live at this depth.

This difficulty then stands opposed to all the theories advanced since the time of Darwin and Dana, and still retains all its force as one of the weightiest arguments in favour of the so-called theory of subsidence. Two objections might be raised to this theory: first, that it is not possible to understand how so large a portion of the earth's surface could have sunk so slowly and uniformly; and next, as Ross pointed out, that among the islands asserted to have subsided stand fragmentary plateaux, which have apparently been elevated. But these facts will no longer appear strange, as soon as we admit that it is not the land but the sea which is the variable element.

As regards the actual amount of the positive excess of the oscillating movement, no estimate, not even approximate, seems to me as yet to be possible. The depth of the lagoons implies positive movement, but there is a wide difference between the 40–60 fathoms of a lagoon (which may, it is true, have been filled up to an unknown extent), and the very considerable depths which have been sounded, not indeed everywhere, but yet in many places, in the immediate neighbourhood of atolls, and which reveal very steep slopes.

That the atolls stand on a rocky base has never been denied. Darwin's description of the relations of barrier reefs to atolls involves this, and the many visible peaks of volcanic mountains testify to it.

Murray has shown what vast quantities of pelagic organisms with calcareous shells occur in certain parts of the Ocean; the shells after the death of the animal fall like rain to the bottom, where they are dissolved by the carbonic acid of the sea-water at great depths, but accumulate in

[1] A. Agassiz, The Tortugas and Florida Reefs; Mem. Am. Acad. Sci., Centennial Volume, Cambridge, 1885, XI, p. 121, maps.

moderate and shallow depths. I believe, however, that the cases are very rare in which this kind of sediment plays an important part in the structure of the substratum of atolls. The mantling over of submarine mountains with limestone is ill suited to explain the isolated atolls in the middle of the Ocean, and volcanic cones would by this means very seldom reach the zone of coral growth. Murray's casual reference to *Graham island* (Julia or Ferdinandea island) seems to me much more fortunate.

This island made its appearance in 1831 as an ash-cone on the south-west of Sicily, in a sea 100 fathoms deep. The waves attacked the mass of loose material, and by the end of a few months a large part had been washed away; the central pipe, filled with scoriae and ash, was exposed. The sea continued its work, and after a short time nothing was left but a slightly submerged bank, which, secure from the destructive action of the breakers, persisted for a long time. In this way a foundation may be prepared at a suitable depth for the settlement of corals. Then all those processes would be set in train which have been described by Semper, Rein, and Murray, and most important the more active growth of those individuals which occupy the margin of the ring.

Some such explanation might possibly hold for the little guano islands, lying near the middle of the Pacific. It is true that some of them, such as Jervis, M'Kean, and Hero islands, are supposed to show signs of negative movement, but the only evidence for this is the presence of gypsum in the lagoon beneath the guano.

Jervis island (lat. 0° 22′ S.; long. 159° 58′ W.) was examined by Hague. A ring-shaped rampart surrounded by a fringing reef rises to a height of +18 to 28 feet. The plain within the ring lies at a height of +7 to 8 feet; it consists of a layer of gypsum covered with guano. In its deepest part gypsum and sea salt occur [1].

On the other hand, Dixon writes of *Malden island* (lat. 4° 2′ S.; long. 154° 58′ W.) that the sea-water percolates through the reef itself into the lagoon, and there evaporates; an outflow only occurs at very low water. Rare but violent showers of rain wash the salt out of the lagoon but leave the gypsum behind. The rampart attains a height of +21 feet. Ancient kitchen middens are found on this island. Several concentric ridges, formed of loose blocks of reef rock, succeed each other both on the north and south side of the island; they run parallel with the shore, and have been piled up by waves of unusual power [2].

Not only the waves produced by storms, but those due to earthquakes, which travel from time to time across the Ocean, must doubtless leave

[1] J. D. Hague, On the Guano Islands of the Pacific Ocean; Am. Journ. Sci. Arts, 1862, 2nd ser., XXXIV, pp. 224–243, in particular p. 230.

[2] W. A. Dixon, Notes on the Meteorology and Natural History of a Guano Island; Journ. Roy. Soc. N.S.W., 1878, XI, pp. 165–175.

their traces on the strand. The occurrence of negative positive movement in these isolated spots cannot therefore be regarded as ascertained.

It follows from the foregoing observations that the substructure of the coral islands is of various nature and age. Volcanos are still active, and new bases for the attachment of corals are continually being formed. But the settlement of the polyps on the summit of a few isolated ash-cones can only account for some of the reefs. Many may be seen resting on fragments of ancient continental land; from others the peaks of volcanic masses project, showing that loose ash-cones have not formed the only basis of support. The deeply eroded valleys of these peaks may in all cases, according to Dana, be regarded as an indication of positive movement. The rule that in the Atlantic Ocean the islands are arranged in straight lines, and in the Pacific in arcs, has its cause deep in the original structure of the globe (II, p. 205). It applies as much to fragments of folded cordilleras as to the alinement of volcanic series and the distribution of coral reefs. The volcanic line of Fernando Po is straight, and the lines of coral reefs in the Maldives and Laccadives are straight also. In the west Pacific all the islands, whatever their constitution may be, are arranged in arcs. Thus the coral reefs disclose to us the plan on which the heights beneath the sea are distributed, or, in other words, *by means of the coral reefs an isohypsis of the submerged mountains of the Ocean is projected on its surface.* This important fact affords, however, strong support to the theory that the coral reefs have been produced under the influence of positive movements, and there is nothing to indicate that the peaks and crests of the submarine mountains are of equal height. However frail may be the arguments on which Darwin and Dana have based their rough estimates of the thickness of such structures, yet it must be observed that the figures they obtained, viz. 1,150, 1,750, and 2,000 feet, are well within the thickness of the stratified masses of limestone and dolomite, which accumulated over a large region of the Alps during the epoch of the Plattenkalk alone, i. e. of an upper division of the Keuper. But that the sea of the Plattenkalk, at least towards its close, was subject to oscillations with a positive excess seems to me to have been established. Oscillations may be deduced from the precise observations made by Rink on the Nicobar islands, by Junghuhn and von Richthofen on the reef of Udjong-Tji-Laut-urun on the south coast of Java, and by von Drasche in the neighbourhood of Paracali on the east coast of Luzon. In the last two cases a dead reef may be seen separated from the land by a plain of coral sand. Outside the dead reef is the living reef bathed in the wash of the surf[1]. I regard all the tabular masses of dead coral rock, which rise to

[1] H. Rink, Die Nikobarischen Inseln, 8vo, Kopenhagen, 1847, p. 82 et seq.; Junghuhn, Java, III, p. 1442; Richthofen, Zeitschr. deutsch. geol. Ges., 1874, XXVI, p. 240; Drasche, Luzon, p. 62, and fig. 14.

a height of 100 meters and extend as far as the remote Henderson island, as indications of ancient oscillations. Unfortunately, we do not possess any detailed description of the organic remains found in these islands. In the Atlantic, outside the region of the reefs and to the north of them, sediments have been laid bare in the same manner on the Azores and Madeira; and these have been referred to the first Mediterranean stage, i. e. to one of the lower subdivisions of the Miocene. In Madeira (lat. 32° 43′ N.) they rise to a much higher level than the fragments of the Pacific plateaux, attaining a height of 1,350 feet (I, p. 288).

Darwin, I think, went too far when he attempted to distinguish regions of elevation from those of subsidence by plotting the distribution of fringing reefs, barrier reefs, and atolls; Dana has already expressed the same opinion, but the attempt which Dana also made to determine regions of maximum subsidence according to the number and size of the atolls does not rest on a surer basis. On the other hand, in spite of the extremely valuable information accumulated by recent observers, I believe, in agreement with F. von Richthofen, that we must still accept as a true explanation the fundamental idea of the subsidence theory, according to which the larger coral reefs have been built up under the influence of a widely distributed oscillation of the strand, with a positive excess[1].

This movement, if it still continues, must take place so slowly as to be beyond the reach of measurement, so slowly indeed that little reefs, like the Tortugas, the atolls of Mahlos Mahdu and other islets, may come into existence without betraying any signs of its action.

Thus we have reason to believe that *these reefs have arisen under the influence of a predominant positive movement*, and on the other hand those who maintain that *no movement is taking place at the present day* are right, in so far as no such movement can be directly demonstrated.

It has been repeatedly asserted that Darwin's views are not in accordance with what is known as to the mode of occurrence of corals in ancient marine deposits. I have made a personal study of all the more important and well-known coral formations in the Gosau beds, the Eocene of Cormons, the Oligocene of Crosara and Castel Gomberto, yet notwithstanding the abundance and variety of the corals, sometimes forming really large isolated growths, I have never seen anything in these localities which could be called a true coral reef. The corals lie heaped together, with shells, in tuffs or marls, that is, always in clastic sediments. The loose nature of this material renders the corals an easy spoil, consequently they are abundantly represented in collections, and hence the reputation of these localities. Coral reefs must be looked for in hard limestone, but in these late Neozoic formations I know of no masses of limestone which could be termed reefs in the true sense of the word. The only conclusion to be drawn from this

[1] F. von Richthofen, Führer für Forschungsreisende, p. 406 et seq.

is that at this period the requisite conditions for the growth of reefs did not exist in Europe.

In the Rhaetic stage there are marly beds which have afforded corals, and the Rhaetic zone of the southern Alps contains reef-building species, such as *Convexastraea Azzarolae*, *Thamnastraea Meriani*, and *Astraeomorpha Bastiani*, which also occur in the northern Alps[1]. But these species, buried in marl, do not form coral reefs. To discover anything like continuous growths we must examine the underlying or intercalated Lithodendron limestone; here we may see masses 15 to 20 meters thick, or perhaps even more, which are actually formed of the cylindrical corallites of Lithodendron; but these also, as far as I have been able to observe them, have rather the appearance of thick beds than of true reefs. The arrangement in beds is predominant, and the resemblance to the beds of Sombrero or to the incrusting coral growth on the calcareous mud of Florida bay is unmistakable. The evidence presented by these ancient sediments of the deposition of dolomite, as such, directly from the sea is, however, of the clearest nature. Agassiz says that the fine calcareous mud suffocates and kills the corals. On the Osterhorn corals occur in a white dolomite, and their calyces are filled with dark coloured dolomite, which has entered them from above[2].

The existing structures which are most closely allied to the coral beds of south Tyrol are perhaps the older tabular masses which now project from the middle of recent reefs, but there is no reason to suppose that the beds in south Tyrol were surrounded by similar reefs. With the exception of those places where interbedding with adjacent tuffs occurs, and where we appear to have to do simply with an interrupted formation of limestone, these tabular fragments had the form of islands.

6. *General Survey.* We have referred to only a very few of the remarkable events which distinguish the history of the Tertiary aera. Towards the close of the Cretaceous period, but before it had actually come to an end, a great and progressive decrease in the extent of the sea began to take place. In the middle of the central Mediterranean and in the Sahara we can discern no trace of this; there, marine sediments succeed each other without interruption. But around these regions large areas were laid dry, fresh-water formations accumulated: on the one hand the Garumnian series, which extended on both sides of the Pyrenees and into the valley of the Rhone, on the other the contemporaneous Liburnian series, which covered the region north of the Adriatic; these show how great the negative movement must have been, and recall the conditions which prevailed at the close of the Jurassic period. The Tertiary sea then advanced by

[1] Reuss, Ueber einige Anthozoen der Kössener Schichten und der alpinen Trias; Sitzungsber. k. Akad. Wiss. Wien, 1864, L, pp. 153–168.

[2] Cf. note 3, p. 263 of the preceding chapter on the suffocation of the corals.

repeated oscillations: in the Oligocene a temporary connexion between Europe and the far north was established along the east slopes of the Ural; then with ever-increasing clearness we perceive the progress of those events by which the ancient central Mediterranean sea was dismembered and diminished. Its communication with India was destroyed. Then it lost Irania, Turkestan, Asia Minor, and the western border of the Alps; the communication, indicated by the sub-littoral fauna, with the West Indies was broken up. Then the Sarmatian region became separated off; finally, not only the Aralo-Caspian region, together with south Russia, but also the valley of the Danube was given up. Next came a period of erosion, when valleys were carved out, and then the Pontic Cardium beds were spread abroad as far as the valley of the Rhone. This is the epoch of greatest shrinkage: the strand stood lower than at present. Then the sea-level began to rise again, and at the arrival of the northern immigrants it exceeded its existing height. Subsidences extended the area of the sea, and the world became much as we see it now. The existing Mediterranean is the residuum of an Ocean, which extended parallel to the equator, and at one time, before the Atlantic came into existence, surrounded half the globe.

There were other marine areas which maintained a protracted existence, but have left no recognizable signs of the manner in which they opened into the Ocean: these were situated over the regions bordering the North sea in the south, in particular the north of Germany and the south-east of England (I, p. 291); but in the whole region of the North Atlantic coast, as well as in North America down to the fortieth parallel, marine Tertiary deposits are wholly absent. North of the Lofoten islands, we enter a region which, as we found when studying the distribution of the Mesozoic seas, is more closely allied with the Pacific than the Atlantic: the Tertiary molluscan fauna of this region, which reveals the temporary advance of the sea across Spitzbergen to east Greenland, where it is associated with the plant-bearing beds, may perhaps have come from the Pacific Ocean by way of Muláto on the lower Yukon. This is a point on which we do not possess as yet any precise information.

The coast of North America, below the fortieth parallel, presents a regular succession of marine Tertiary beds, resting on the Cretaceous, which extends far towards the south; but here also there is a gap. Certain upper members of the Tertiary group are apparently absent, and on the other hand a very recent marine formation occurs in transgression. Here, also, we may fairly suppose that in a late phase of the Tertiary aera the strand-line lay lower than at present, and in the next succeeding phase it again stood higher than it does now.

The Caribbean sea is also a remnant of that great Ocean which once extended parallel to the equator, across the existing Atlantic. This is

shown by the presence of European elements which continued to be introduced into its successive marine faunas, up to the close of the first Mediterranean age. Thus it appears that *those two parts of the Atlantic coast, which in contrast with the rest possess the Pacific structure,* i. e. the cordillera of the Antilles and the broken arc of Gibraltar, *mark the areas once occupied by that ancient Ocean, the 'Central Mediterranean' of Neumayr.*

In the interior of the United States the negative phase, which closes the Cretaceous transgression, is represented by the Laramie stage; great fresh-water lakes existed here during the different periods of the Tertiary aera.

On the Patagonian border of the Atlantic extensive continental deposits with two marine intercalations extend to the sea; they show that the shore was sometimes situated much nearer the cordilleras, sometimes further to the east than the existing coast. The second transgression did not extend so far as the first; but a third marine formation follows the quer-Andinian stage, with a very recent fauna; it rises with continually increasing height as it is traced towards the south. Between the quer-Andinian stage and the last marine Tertiary formation a great hiatus occurs, greater, so far as we can judge, than that of North America, and certainly much greater than that of Europe: and here, also, we find on the whole that at a late stage of the Tertiary aera the strand-line lay lower, and at a still later stage higher than at present.

The Tertiary beds of Chili, of which Philippi has given instructive accounts, I have not ventured to take into consideration. The increase in the height of the quer-Andinian stage towards the south, which similarly occurs in Chili, will be specially considered later. Owing to the fragmentary state of our knowledge I have been compelled to refrain from a discussion of the Tertiary deposits of the Pacific region, and their continuation on the south border of Eurasia, in Java and Sumatra, along the Indus, and in the Persian gulf.

Within the Indian and Atlantic regions the Cretaceous covers the east of Brazil, and proceeds towards the coast without an accompanying Tertiary border. The sea washes against a strip of Cretaceous, which extends, with interruptions, from Piauhy to Bahia, and probably to the Abrolhos. It is the same on the west coast of Africa, from the Elobi islands to Mossamides. In Natal, also, marine Cretaceous deposits advance to the sea unaccompanied by a Tertiary border. The facts are the same in the north-west of India, on the Narbada; and off the mouth of this river lies the little island of Perim, formed of Tertiary sand and gravels, with the remains of Dinotherium, Mastodon, and giraffes—an evidently fluviatile deposit. Near Pondicherry likewise the Cretaceous occurs without a Tertiary border. But associated with these intervals of coast there are others of still greater length, where neither Cretaceous nor Tertiary is seen, but ancient rocks

alone; this is the case in the south of Brazil, as far as and beyond Rio Grande do Sul, in Africa for an unknown distance, in India from the Narbada to cape Comorin, and from Pondicherry to the mouths of the Ganges. The Cuddalore sandstone in the south-west is of comparatively very recent date.

According to all the evidence with which I am acquainted these coasts, distinguished by the absence of an outer Tertiary border, are found chiefly in low latitudes, forming a zone in the Atlantic and Indian regions.

The coral islands of existing seas exhibit in many places relict strand-lines and relict fragments of ancient plateaux; they occupy a region characterized by very extensive and extremely uniform oscillations of the strand-line: the oceanic atolls have attained the surface of the sea owing to the existence of the positive excess. In Florida the foundation of the Keys has been formed by an accumulation of material under the influence of a current. The continuance of a positive phase at the present day cannot be demonstrated from the living reefs, nor is it susceptible of measurement.

With the quer-Andinian stage we reach the most recent transgression known to us: the coral reefs are the result of processes which came into operation at a period immediately antecedent to the present, and are still in progress. I am now obliged to interrupt for a time the historical sequence of this account, in order to discuss certain special points, particularly the strand-lines of the north and the much-debated problem of the temple of Serapis near Pozzuoli. Next, we must consider the different behaviour of incompletely closed seas, such as the Baltic and the Mediterranean, and then we shall be able to return to the most recent transgressions.

CHAPTER VIII

THE STRAND-LINES OF NORWAY

From Tjoalma Vagge to the sea. From lake Torneå to the sea. Movement of the ice contrary to the slope of the valleys. Origin of the glint lakes of Lapland. Ancient strand-lines of the fjords. Origin of the seter. Comparison with Greenland. Vestiges left by the retreating ice.

1. *From Tjoalma Vagge to the sea.* The coasts of northern Norway are marked at intervals by long terraces or grooves cut in the rock. The origin of these terraces and grooves is a question that cannot fail to suggest itself to any observer visiting this region. Since Leopold von Buch's memorable journey at the beginning of the last century, and Bravais' observations on the rise of the strand-line in the Alten fjord, the problem has been made the subject of an extensive literature. The strand-lines in their various forms are not the only problem which here claim attention; another and scarcely less disputed question is associated with it—the origin of the fjords. A glance at the map shows us that unmistakable relations exist between the great lakes of Lapland and some of the valleys which open into the fjords towards the west; some of these lakes themselves actually discharge their water into the Atlantic Ocean. These facts show that we cannot hope to reach definite conclusions as to the phenomena which occur at the mouth of a fjord without a knowledge of its entire valley system from the existing watershed down to the sea.

I have already mentioned in a previous chapter that in attempting a general survey of the connexion between these phenomena I should choose as illustrations those valleys possessing outflows which unite in the Maals Elv and discharge, above lat. 69° N., by a long estuary into the fjord of Malangen (II, p. 58). Leaving the two points we had reached on the watershed, I will now attempt to discuss, after a brief glance at the map (Pl. I), the peculiarities of the valleys and the features which characterize the shore [1].

The Maals Elv is formed by the waters of three main valleys; these are the Ruosta, the Divi, and the Bardo Elv.

[1] The heights marked with an asterisk were determined by means of an excellent aneroid and compared with the observations of the meteorological station at Tromsö. The Director, Herr Hann, was good enough to make the calculations. Other data as to height have been taken from the official map published by the Norwegian Government. In this chapter measurements are frequently given in Norwegian feet; this was almost inevitable on account of the frequent use of whole numbers by the observers (1 Norwegian foot = 0·3137 meter; 1 mile = 11,295·8 meters).

The *Ruosta*, which lies most to the east, is discharged from the glint lake, Ruosta Jaure; it flows at first in a gentle curve to the north-west and west-north-west, and traverses the Lille Ruosta-Vand, at the foot of the Ruosta fjeld (II, Fig. 6, p. 60). From this lake onwards the course of the Maals Elv, so long as it maintains a westerly direction, should evidently be regarded as the continuation of the Ruosta. Beyond the bend of the Maals Elv, the direction of the Ruosta is continued in an unmistakable manner through the elongated lake of Ands-Vand (153·7 meters) into the Solberg fjord. Thus the waters of the Ruosta are diverted under existing conditions and flow through the lower Maals Elv into the Malangen fjord.

The middle river, the *Divi*, is connected by a secondary valley on its right side, the Skakterdal, with the high plateau of Tjoalma Vagge, and in that direction no watershed appears to exist between the river and the glint lake, Tjoalma Jaure. A very remarkable feature is presented on the left side of the Divi by two valleys, which descend at first in a direction opposed to that of the Divi, and conclude by entering it, after swinging round in a sharp bend; these are the valleys of the Anavanda and the Högskar Elv. Near Overgaard, close to the Ruosta Vand, the Divi reaches the upper Maals Elv, which here, as we have seen, is the continuation of the Ruosta, and its waters turn to the west almost at a right angle. But the direction of the Divi to the north-north-west is clearly continued in the chain of larger and smaller lakes, which includes the Fjeld Frösk, Tagvand (220 meters) and Sagelvand (90 meters), and terminates in the Sörkjösen in the Bals fjord and the Nord fjord in Malangen. Thus the Divi, like the Ruosta, is twice diverted from its original course; the direction of which is continued by a chain of lakes standing at a higher level.

The third river, the *Bardo*, includes two reaches, an upper and a lower. The upper runs to the north-west, and its higher part is the glint lake, 48 kilometers long, which arises from the junction of the Lönnes Jaure (Lejna Vand) and the Alte Vand (516 meters). This great sheet of water, which is evidently only an enlarged river course, flows to the north-west towards the Atlantic Ocean, but parallel to it and close beside it lies the Gievne Jaure, 16 kilometers long, which flows out towards the south-east, like most of the glint lakes which discharge into the Baltic, but in this case the outflow bends round in a sharp curve to join the Lönnes Jaure, and thus precisely repeats the behaviour of the lateral valleys on the left side of the Divi. This upper reach of the Bardo receives the northwards-flowing Sördal Elv, which runs in a deep bed from the watershed close to the lake of Torneå. Near the parish of Bardo the north-westerly running upper branch of the Bardo Elv terminates, and the valley takes a north-north-east direction. At this place there is a very low col, which passes from Bardo westward to the Salangen Elv, the upper lake of Salangen, and the Salangen fjord. But the river itself now enters its lower reach below

Bardo, runs to the north-north-east, and encounters almost at right angles the direction of the Ruosta; while the lower Maals Elv, together with its estuary, proceeds to the north.

Thus our first glance at the map reveals a peculiarity of fundamental importance in the study of this region, where *successive valley systems have been superimposed one upon another.* The river valleys are continued in long troughs, which are occupied by lakes and lie several hundred feet below them; thus the Ruosta is continued into the Solberg fjord, the Divi with equal clearness into the chain of lakes which extend from the Tag Vand to the Bals fjord, and the upper Bardo in all probability to the west, towards Salangen. I may at once mention that these higher lying basins are all, so far as I am acquainted with them, without exception remnants of excavated glacier beds. The ice filled all the hollows of the mountains and moved forwards in them, *but the running water which supervened selected only a part of the glacial valley system, and deepened that only.* The remaining part, lying at a higher level, has been left behind in broken chains of lakes.

We are now able to interpret these valley systems, different in age and disposed at different levels. The oldest and least known is the pre-glacial valley system. Fragments of it are represented by Anavandene, Högskar Elv, and Gievne Jaure, where the ancient slope to the south-east is preserved. With the advent of the glacial epoch the ancient channels were filled with ice, and enlarged after a plan which depended on the direction and damming back of the ice, but not on the fall of the pre-existing valleys. Thus the second or glacial valley system arose. The third is the existing system, which the rivers are still shaping out.

Nearly the whole region of these valleys is included within the flat-bedded ancient table-land, the structure of which has already been described. The band of gabbro and eclogite, which strikes from Lyngen obliquely across the valley of the Maals Elv towards the Istind in Bardo, appears to have had no influence on the formation of the valleys. The table-land terminates on the Swedish side in that steep descent we have termed the Lapland glint, and the great lakes are true glint lakes lying across the slope; thus the glint runs across the middle of lake Torneå, across the Gievne Jaure and the Alte Vand. In the valley of the upper Divi the ancient foundation, according to Pettersen, extends somewhat further to the north; on Tjoalma Vagge the glint is broken up into great bastion-like table mountains (II, Fig. 7, p. 61), and thence it proceeds further to the Ruosta Jaure. Thus these lakes, whether they discharge into the Baltic sea or the Atlantic Ocean, follow the general rule and extend transversely across the glint.

The movement of the ice, however, so far as I could discover, was everywhere directed towards the Atlantic: more to the south it needed

the laborious investigations of Hörbye and his successors to show that the highest level of the ice-mass lay east of the existing watershed; but here in the north the fact is obvious at first sight, and if any doubt were felt it would be at once removed by the conspicuous blocks of red Swedish granite which have been carried in immense numbers across the glint, and through its portals, on to the Norwegian table-land.

Let us now examine the country a little more closely.

Our first traverse runs from Tjoalma Vagge through the Skakterdal and Divi across the chain of lakes of the Tag Vand and Sagel Vand to the Bals fjord. This is the same line as that we have already described, at least as regards its more elevated part in a previous chapter (II, p. 60).

On the lofty barren surface of the Tjoalma Vagge we are surrounded by a boundless labyrinth of low mounds of stones. Peat bogs and numberless pools of water broaden out between them. Low rounded bosses of red granite project from the mass of débris, and reveal the fact that we are standing on the foundation of the table-land. This is moraine land. No one can say exactly where the watershed lies between the Baltic sea and the Atlantic Ocean, the latter as the crow flies only 77 to 80 kilometers away. In the season when the snow melts all this country is probably inundated; nothing but a few stony ridges, higher than the rest, will rise above the water here and there, and the direction of the outflow will depend upon the wind.

Towards the north, west, and south-west rise like phantoms the great cubical masses into which the glint is broken up; far away the outlines of the table mountains are veiled in mist, and through the mist their snowfields glisten. The foot of the nearest mountain, Store Jerta, is surrounded by a terrace, about 15 to 20 meters high. Whether this little cliff, which faces the labyrinth of stony mounds, indicates the border of a once continuous and permanent sheet of water or of a temporary inundation is a question I will not pretend to answer. (Upper edge, 723·4 meters.*)

A chain of pools, united by a thread of water, extends towards the portal between the table mountains Store Jerta and Namna. The breadth of this is scarcely more than 800 meters, at the level of the route by which we pass through it, and this is no great height above the bottom. We stand here at one of the passages through which the ice advanced towards Norway. To-day it presents the aspect of a glacier bed, scarcely changed. Remnants of the moraines of Tjoalma Vagge appear to penetrate into the portal; they are broken up into barren isolated sand-hills with somewhat steep slopes scattered here and there over the ground. Higher up on the slopes of both mountains, particularly of the Namna, we see several long mounds of sand, more like dunes than moraines, which evidently slope downwards, that is, with the water drainage. At one spot we see five or

six of these ridges on the Namna, resting obliquely one against the other. They are the vestiges of the last movement of the ice in the pass. Herr Pettersen has ascended the Store Jerta and found blocks of the red granite from Sweden on its summit; there was thus a time when the great pylons of the portal were overwhelmed by the ice.

Where the land widens out below and at the mouth of the pass, hundreds of circles, two to four meters in diameter, are scattered over the surface; this is enchanted ground, a dancing place for the elves; so such spots figure in folklore: but in fact the circles are formed by colonies of grass, which grow outwards at the margin and die away in the middle, a sort of vegetable atoll[1].

We have now walked round the Store Jerta; the finer débris, and with it the fairy circles, is gone, and we stand on a broad glacier bed. In a little hollow are seen the first stunted birches (599·6 meters*); beyond it polished surfaces extend far and wide. These are great moutonnéed bosses of schist and quartzite, and although the whole region is flat-bedded, yet violent local foldings are revealed on the polished surfaces of the rocks. Over the roches moutonnées erratic blocks are scattered in a strangely uniform manner, we might almost say at equal distances. The blocks consist chiefly of red granite: as a rule they are somewhat less than a cubic meter in size; some of them larger. They lie on and between the roches moutonnées just as the ice has left them, and sometimes the pressure of the hand is sufficient to send a heavy mass clattering down from the summit of the boss on which it rests. The moutonnéed surface may be recognized on the slope at our right for a height of at least 100 meters above us.

On this part of the glacier floor sand and small stones are rare, and the regular distribution of the blocks on the roches moutonnées does not correspond with the ideas generally entertained as to the nature of a ground moraine. While here everything looks so fresh and undisturbed, on our right the brook which issues from the portal, and in the interval has become the raging Skakter, has already excavated in the same rocky ground a ravine more than 100 feet deep.

We now proceed along the gentle slope of the glacier bed, when it suddenly comes to an end. A low cliff of flat-bedded quartzite follows; below this a spring, and then a steep wooded descent into the valley of the Divi. At the bottom we see the cone built up of the material which the Skakter has brought out of the ravine, and then the rushing Divi.

[1] Professor von Kerner tells me that *Sessleria coerulea* is the plant which generally forms these fairy rings, and that the destruction of the vegetation within the green border is produced in two ways: in the case of plants with radially extending rhizomes the older parts of the rhizome die and decay at the centre, and new plants do not immediately take their place; secondly, the meadow grasses are killed by the mycelium of a fungus which accompanies the radial growth.

The Dividal is a rectilinear narrow valley; its whole length amounts to about 60 kilometers, of which 36 go to the reach below the mouth of the Skakter valley. The hut of Frihedsli (187 meters*), stationed in the virgin forest of the valley bottom, was the starting-point of our wanderings. Here in August we found flowery meadows, a noble forest growth of birch, butterflies, and in the short twilight even bats, and only the trifling height to which the wood extends up the mountains reminded us that we were in the latitude of central Greenland. The mountains which surround the middle Dividal are 4,000 to 5,000 feet in height (Njunnes Vane opposite Frihedsli, 1668·6 meters), and throughout the year are covered with more or less extensive sheets of snow. If we ascend the slope of the Anaskole above Frihedsli we find that both sides of the valley up to a certain fairly uniform level are formed of a continuous sheet of débris: I put its height above the valley bottom at 200 to 250 meters. In this débris we also find fragments of red Swedish granite: we might regard it as a marginal moraine, but it nowhere rises in mounds from the rocky walls of the valley.

Through the narrow valley bottom rushes the Divi Elv. I do not think it would be exaggerating to say that the volume of its waters is probably six to eight times as great as would be met with under similar conditions of topography in a valley of the Alps. The high rainfall, the great quantity of snow which accumulates during the long winter, and the length of the day in summer are responsible for this extraordinary volume of water, and explain the great and unusual power of erosion.

After a walk of some hours down from Frihedsli we reach a somewhat broader valley bottom, and here the first settlements have been made. The river is bordered by regular terraces; two or even three occur one above the other. They have undoubtedly been formed by the river itself; this is apparent from the fact that ox-bow terraces, that is islands of alluvium which have been left in place, occur on the older terraces. Such isolated spur-shaped fragments of terraces can only have been left by running water, and indeed by the displacement of the river bed. They overlook the adjacent valley bottom; several of the farms have been built on the terminal spur of one of these ox-bow terraces.

Towards the end of the valley the Divi enters a ravine; on the left we ascend a ridge, presenting in its lower part moutonnéed bosses of schist and quartzite; above, an accumulation of blocks, probably part of a moraine, which, however, lies higher than the valley bottom of the Divi; on the other side the road runs down towards Overgaard (58·6 meters*), where the Divi joins the Maals Elv; here also river terraces occur.

We cross the low-lying terraced river valley and enter the ancient prolongation of the Dividal toward Bals fjord indicated by the lakes. This, as we have seen, is a glacier bed. Pettersen has also recognized the

fact that the ice which came down the Dividal crossed the valley of the Maals Elv and proceeded towards Bals fjord, and consequently that the valley of the Maals Elv has been deepened subsequently by erosion; he showed besides that on the right side of this glacier bed blocks of red granite occur nearly up to the summit of the Omasvane, and on the left they cover the slopes of the great Mauktind, which is much higher than the Omasvane, to about 2,500 feet above the sea, or as far as it has been examined [1]. The ice as it passed through this trough must thus have been of great thickness. The terraces of the river valley have now disappeared; roches moutonnées surround us on all sides. Their smooth and rounded summits protrude from the peat bogs which surround the green waters of the Lompol Vand, and accompany us as far as the islet-strewn waters of the Tag Vand (173·3 meters), which wash against the foot of the Mauktind; the rocky slopes, as we can plainly see, are likewise polished to a great height above us. Beyond the Tag Vand the country presents peculiarly characteristic features. On the slopes of the Omasvane we wade through high ferns; a few beeches remind us of our own land: but on the left lies the bare U-shaped, polished glacier bed with its rounded bosses, and in between them innumerable little pools of water which drain partly into the Tag Vand and partly into the Sagel Vand to the north; they are the most remote retreats to which the salmon ascend. No channel of any depth is to be seen; travelled blocks are strewn around: it is alsolutely impossible to suppose that this glacier bed can have been covered by the sea since the retreat of the ice, and that the scene should have remained so completely unchanged, the glacial striae so fresh, the little hollows between the bosses unsilted up, and the scattered blocks undisturbed, notwithstanding the play of the tides. And yet this glacier floor here lies only 130 to 150 meters * above the sea, and descends lower and lower as we proceed.

Above the farm of Myre, nearly 400 feet above the sea, we still find the hard schists quite sharply marked with glacial striae directed down the valley, and below the farms the roches moutonnées and travelled blocks, amongst them red granite, lift their heads above the peat bog, which stretches away as far as the Sagel Vand. The bed of the glacier has sloped gradually down to the level of the Sagel Vand (90 meters).

The Sagel Vand is the last lake that we meet with along this traverse; it is said to be 220 feet in depth, so that its bottom lies a little below the existing level of the sea. On its right we observe what appears to be a bit of lateral moraine, and at its lower end are indications of a terminal moraine, but as to this I am not certain. With this lake the U-shaped valley comes to an end. Recent alluvial land evidently forms a considerable part of its

[1] K. Pettersen, Det nordlige Norge under den glaciale og post glaciale Tid: III, Granitisk flytblokkeström udefter Balsfjorden; Tromsö Mus. Aarsh., 1884, VII, pp. 1–12.

lower termination, although rounded bosses of rock project from it. The alluvial land, formed of sand and gravel, extends below the lake in a plain, which broadens out downwards: we proceed along this plain for a distance of 4·5 kilometers, and then before us lies the Bals fjord. We now find ourselves on the upper edge of a slope, which towards the sea is divided into two sharply defined terraces.

A result of great importance follows from all these observations. The ice-streams which entered the country from Sweden, flowing through the portals of the glint and above them, had their bed at a higher level than a great part of the existing Dividal and the existing valley of the Maals Elv. We have traced this bed through the upper Skakterdal, as far as the steep descent to the Dividal. Its continuation is seen in the U-shaped trough of the Tag Vand, where it is much deeper than in the portal, but still some hundreds of feet above the existing valley. The slope of this glacier is directed towards the Bals fjord. *Its polished bed, after its level has fallen to* 90 *meters, sinks beneath the waters of the Sagel Vand; this is held up on the seaward side by a dam, formed perhaps by a terminal moraine, and certainly by the alluvial land, in which the terraces of the Bals fjord have been carved out.*

The terraces at the time I crossed them afforded some excellent sections, exposed in the construction of a new road. They consist of angular sand with pockets of small pebbles in considerable quantity. The pocket-like intercalations are obliquely inclined, and more steeply than the outer slope of the terrace. Among the pebbles some well-worn fragments of the red granite occur. Now and then a red block of some size may be seen; Herr Pettersen thinks that such blocks have fallen from the top of the slope. The presence of small rounded pieces of carbonized wood in the sand caused me the greatest surprise; they prove the existence of trees during the deposition of the sand. I could find no trace of marine animals.

Let us descend now to the sea.

2. *From lake Torneå to the sea.* At the northern end of the great lake of Torneå (319·2 meters*) a fisherman's hut, rarely occupied, is for miles around the only shelter, with the exception of the temporary encampments of the wandering Lapps. The hut is surrounded by an accumulation of great blocks; gneiss, ancient schist, and even the red granite occur, but the last is not so prevalent as in the region of the Divi. The accumulation looks as if it had been pushed out from the lake; but, while in other cases moraines occur as dams at the lower end of a lake, here the accumulation is situated at the upper end. The promontory which projects into the lake from its lower and northern side, south-west of the hut, consists of quartzite, and forms part of the flat-bedded table-land, which surrounds this part of the lake. We ride a little distance along the moraine to reach the ridge of quartzite. Where it joins the land it is lower; the depression is occupied

by an ancient reindeer enclosure, strongly built, which bars the way. Beyond it, quite rounded by the ice, rises the isolated quartzite hill, Polno-Röset, also called Rös, the boundary point number 272 on the frontier of Sweden and Norway[1]. Directly below the Rös, in a deeply glaciated hollow, lie pools of water, without exit, between rounded bosses; this is the watershed (390·5 meters*), only 71·3 meters above the lake. On the right it slopes down to the lake; on the left we look into the upper part of the deep ravine which the Sör Elv has sawn out in the glacier bed, and through this it flings itself into the Sördal. If this torrent should also succeed in cutting through the col below Polno-Röset, a task in which the great masses of snow accumulated every year in this hollow will assist, then lake Torneå will be added to the Atlantic region, like its higher lying neighbours in the north-east.

The ravine of the Sör Elv is impassable, and we ascend the slope on its right, which surrounds the northern end of the lake. Rounded hills of débris, thinly covered with birch wood, are scattered over the slope. The trees soon disappear, and we reach the summit of the Stagenuni pass (782 meters*) high above the watershed. We find ourselves once more in a U-shaped eroded trough; roches moutonnées surround us, and all the signs of a glacier bed are present. The roches moutonnées occur on the slopes of the flat-bedded mountains of schist and quartzite up to a height of at least 100 meters above us; in the bottom of the glacier bed the Sör Elv has cut its way. There can be no doubt that the ice moved to the north, contrary to the existing outfall of lake Torneå, and, advancing against the existing slope, crossed the whole region from the bottom of the lake up to the trough of Stagenuni. Polno-Röset and the watershed lie at a locus of especially severe erosion; but the threshold above the lake, that is the bottom of the U, lies at least 200 meters above its surface. This height, to which we must add the depth of the lake, must have been surmounted by the ice.

Stagenuni also lies in a portal, which is distinguished, however, from that of Tjoalma Vagge, not only by its great threshold, but also by its greater breadth. The table mountains on both sides of the upper Sördal, Rissovarre with the Duoddarats on the right, and Nunnis, Spikalomi, and others on the left, stand much further apart; the Sör Elv, however, like the Skakter, has cut for itself a deep ravine. The destruction of the upper part of the glacier bed by running water is very evident. Let us turn our attention to the right bank. Below the high, well-stratified, and rocky peaks, a shoulder rises like a very broad shelf. It is the upper part of the

[1] At this point stone tablets bearing the royal monograms and the dates 1763 and 1827 have been inserted into a pyramidal pile of stones; to right and left what forest there is has been cut down along the line of the frontier, leaving a trail like a broad road—a peculiar sight in this wild country.

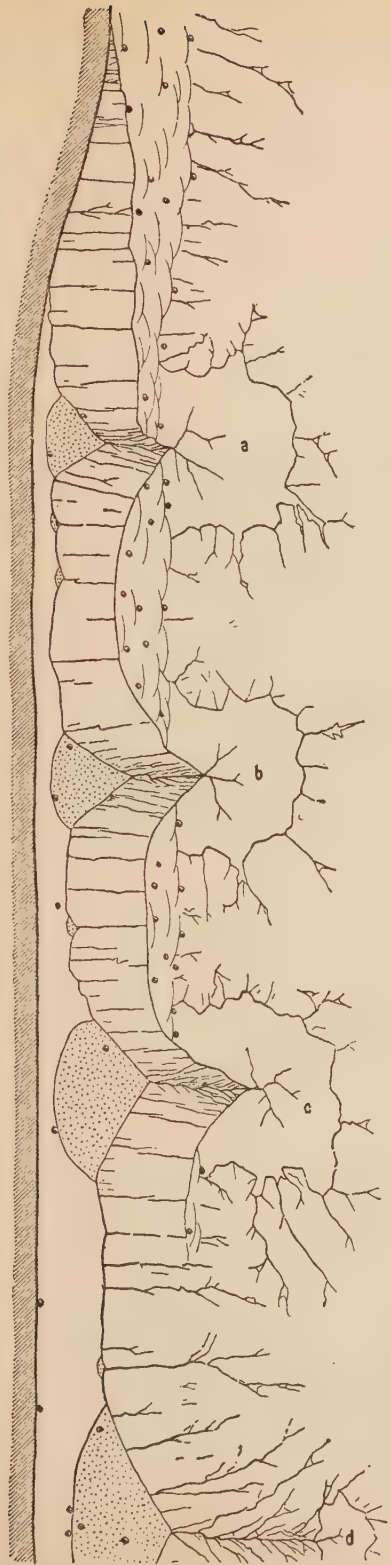


FIG. 32. *Diagrammatic sketch of the left side of the upper Sördal.*
a, b, c, d Snowfields, which feed the torrents, thereby destroying the glacier bed (the shoulder) and themselves at the same time.

polished glacier bed sharply marked off from the precipitous slopes above. It may be clearly seen running from the north-west border of lake Torneå, below and around the summit of the Nunnis, and far above the existing watershed into the upper Sördal. It represents what is left of the U of the glacier bed. Furthermore, between every two peaks lies a little hollow, and in the hollow and on the shoulder is a snowfield (*a, b, c, d,* Fig. 32); out of each snowfield issues a brook; and each brook becomes a roaring torrent as it precipitates itself into the principal channel of the Sör Elv, wearing away and destroying the shoulder between the two peaks, and at the same time the snowfield which feeds it. One of them, broken up by the high fall, fills a great part of the narrow valley with clouds of spray. Thus the first peak is surrounded by a fairly broad shoulder which ends abruptly against the ravine of the Sör Elv, and is cut back by the waterfall; the second peak is bordered by a smaller fragment of the shoulder; still smaller is the fragment beneath the third peak; on the fourth, the shoulder has practically disappeared. The glacier bed is no longer visible: its sole surviving vestiges are heaps of débris and occasional blocks of red granite scattered along the valley walls. From this point onwards the existing valley owes its origin solely to running water and the weather. In the same manner the great slopes of débris which occur in the

Dividal have no doubt arisen. Thus the U-shaped valley gives place to a V-shaped valley lying at a much lower level, and at the same time the table-land is resolved into a number of isolated mountains.

The Sördal cuts its bed deep. The first farm, Sörgaard, 17·4 kilometers below Polno-Röset, and about 13 kilometers below the point measured on Stagenuni, lies only 103·3 meters * above the sea. At this point the glacier bed, which has already disappeared far above Sörgaard, was situated more than 300 meters above the existing valley bottom. So stupendous has been the work of running water since the retreat of the ice [1].

About 25 kilometers below Polno-Röset the valley broadens out, and we soon reach the Bardo Elv: now terraces occur, and the second farm, Strömsmoen, stands only 61·5 meters above the sea [2].

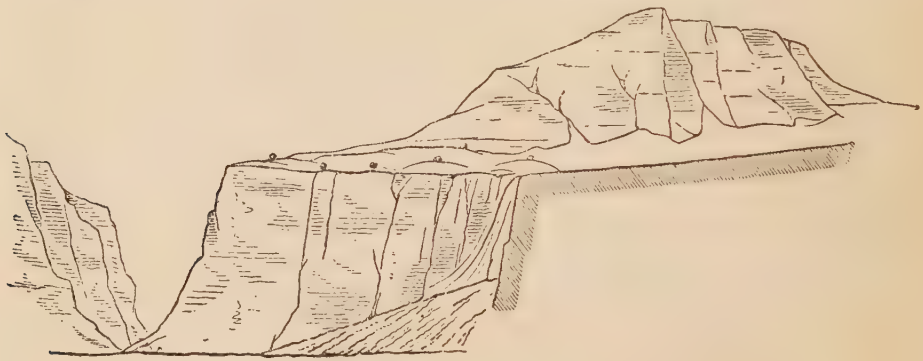


FIG. 33. *Diagrammatic section across the left side of the upper Sördal.*

At Strömsmoen we meet the Bardo Elv in its course from the Alte Vand; terraces occur in great number, and where the river approaches the Maals Elv a broad step, formed of fine sand, covers a wide area. In this terraced valley we stand, as it were, beneath the ancient glacier bed: indeed, the indefatigable Pettersen has found roches moutonnées to the right of the valley, just below the parish of Bardo, where they reach a considerable height on the mountain of Graahogden: blocks of the red granite were observed by him as far up as 2,200 feet, and on the left side of the valley at a height of 3,000 feet on the Store Ala [3].

[1] In 1875, near Sörgaard, a mighty fragment, larger than a house, broke away from the quartzite cliff and fell from top to bottom; to the astonishment of the inhabitants it rebounded from the meadow below far into the valley; there it still lies completely isolated.

[2] This number differs essentially from that of the Norwegian official map (341 feet = 106·9 meters); it is the mean of three measurements made on different days. I must leave the discrepancy to subsequent observers. If Strömsmoen is situated at 106·9 meters, then Sörgaard must necessarily lie higher than 103·3 meters; here also my figure is the mean of two closely concordant measurements.

[3] K. Pettersen, Det nordlige Norge, etc.: VIII, Bardodalen and XI, Granitisk flytblok-

The Maals Elv is likewise bordered by terraces, but in its lower reaches, from Bakkehaug onwards, stiff blue clay in addition to sand and gravel contributes here and there to their formation; this is particularly the case at their base, near the river, below Moen in the parish of Maals-Elven. Below Maals-Elven the terraces still present those bow-like excisions, so characteristic of the windings of a river, which are known in America as 'ox-bends.' From here onwards the blue clay predominates; near Guldhåv, at the commencement of the estuary, roches moutonnées again make their appearance; the glacier bed has reached the level of the sea and the blue clay of the estuary lies over its hummocks. A long rocky spur extends northwards into the sea as far as Maalsnäs, and blocks of rock form so great an accumulation on its slopes that we might almost imagine a moraine

FIG. 34. *The Seven Sisters.*
A rock (nunatak) once projecting out of the ice-sheet; seen from the sea.

had here reached the sea. Some of the blocks consist of red Swedish granite.

3. *Movement of the ice against the slope of the valleys.* It is now well known, as a result of the laborious investigations of Norwegian geologists, the comprehensive studies of Kjerulf in particular, that the evidence left by the ancient ice-sheet in south Norway, west of the Christiania fjord, indicates an almost radiate movement directed towards the sea; east of the fjord the approximately radiate arrangement of the flow-lines is repeated, but with another centre of dispersion[1]. At the same time a certain correspondence between the direction of flow and the existing form of the surface is on the whole unmistakable in this region. More to the north

keström udefter Maalselv, Bardo og Salangsdal; Tromsö Mus. Aarsh., 1885, VIII, pp. 1–4 and 23–38.

[1] T. Kjerulf, Om Skuringsmærker, Glacialformationen, Terrasser og Strandlinier; Univers. Progr. f. and. Halvaar 1872, 4to, Christiania, 1873, and in other publications.

the case is very different. There the ice moved for great distances in a direction opposed to the existing slope of the valleys. The fact is so remarkable that earlier observers thought a subsequent and unequal elevation of Scandinavia was required to explain it.

That the direction of the striae indicates a consistent system, which, however, included a movement *from below upwards* extending for a great distance towards the existing watershed, was already known to Durocher, although he attributed the whole phenomenon to floating ice[1]; the facts were admirably stated by Hörbye in 1887[2]. Even at that time it was recognized that from about lat. 62° N. onwards, the abraded rocks on the southern slopes of the Dovrefjeld stood with their stoss[3] sides facing towards the south, and the movement must consequently have been directed to the north; beyond the Stor Sjön, from lat. 62° to 63° 30′ N., the same opposition between the direction of the existing water channels and the ancient striae was observed by Durocher; Suhrland showed that between lat. 65° and 66° N. the striae extend across the watershed towards the west and north-west into the Vefsendal, which reaches the sea near the Seven Sisters (lat. 66° N.); he also observed striation running in a westerly and north-westerly direction across the group of lakes of the Valta Jaure, which marks the watershed between the region of the Luleå-Träsk and the Tys fjord in lat. 68° N.

At that time, when doubt was still felt as to whether the striation was really due to ice, it was already clear that the effective agent, whatever its nature, had moved *from below upwards* over a great distance. To-day these observations compel us to the conclusion that the summit of the great ice cap lay east of the existing watershed and at some height above it.

It is to this fact, as Hansen has shown, that the formation of terraces and strand-lines on the slopes must be ascribed[4]. On the south side of the Dovrefjeld, especially near the head-waters of the Glommen, we meet with great horizontal terraces of alluvial land; they lie from 657 to 1,090 meters above the sea, and are sometimes associated with a cutting back of the solid rock. This chamfering does not produce true grooves, but

[1] J. Durocher, Études sur les phénomènes erratiques de la Scandinavie; Bull. Soc. géol. de Fr., 1846–1847, 2e sér., IV, pp. 29–89 et passim.

[2] J. C. Hörbye, Forsætte Iagtaggelser over de erratiske Phænomener, Nyt Mag. Naturvid., X, 25 pp., map; and in particular by the same, Observations sur les phénomènes d'érosion en Norvège, publié par B. M. Keilhau, Progr. de l'Univ. de Christiania pour le 1er sém. 1857, 4to, 56 pp., maps, in particular pp. 23, 24.

[3] As we have no equivalent in English to indicate the face of a rock which is opposed to the flow of the ice I propose to adopt this term from the German; it has become almost as necessary as its correlative 'roches moutonnées.'—Note by Editor.

[4] A. M. Hansen, Om seter eller strandlinjer i store höider over Havet; Arch. Math. Naturvid., 1885, X, pp. 329–352, map.

horizontal shelves not unlike narrow steps: they are called *seter* or *sätar*, that is benches or seats, and since I know of no other characteristic expression for these features, I will adopt this term.

At heights such as those at which the terraces occur, the remains of marine organisms have never yet been encountered. The high valleys with their steps now lie freely open to all the country below, but their seter and terraces are horizontal. There must, therefore, at one time have been a temporary barrier closing them in.

The area characterized by striation directed towards the north, that is up the valleys, and by the corresponding transport of travelled blocks, is bounded on the south by a line which in the region of the Gudbransdalen and Oesterdalen lies far to the south and south-east of the existing watershed. When the retreat of the ice began, the uppermost parts of the valleys, lying nearest the watershed, must have been the first to be exposed; since the summit line of the ice-sheet did not coincide with the watershed. Lower down they were still closed by the ice; thus high-level lakes were formed, and in them the high-level terraces and seter. The diurnal changes of temperature at the level of the water led to the formation of the seter.

The phenomena of the Dovrefjeld are repeated in Jemtland. Törnebohm has confirmed Durocher's observations as to the direction of the striae; Högbom has traced the direction with even greater precision. The movement of the inland ice from Ångermanland through north Jemtland was towards the south, in south Jemtland towards the north. Thus two opposing streams encountered each other somewhere between the eastern part of the existing Stor Sjön and the neighbourhood of Ström, and they were diverted to the west and south-east. The direction of the striation and the evidence of the travelled blocks combine to show that one especially great movement proceeded towards the west, that is, obliquely across the direction of the existing Kall Sjön into Norway. Although, as is shown by the transported blocks, many of the most considerable heights were covered by the ice, yet the steep slopes, which bound the west side of the Stor Sjön, have affected the lower part of its flow, and produced a somewhat sharp deflexion of the southern ice-stream, turning it from the north-north-west towards the west: the chief movement has thus passed as it were through a broad portal along the lower lying regions near Åreskutan and across the existing watershed[1].

Here also, according to Högbom, horizontal lines occur on the west side of the Stor Sjön: traces of terraces appear to surround Åreskutan: these may be clearly seen on the Kall Sjön. Here also as the ice retreated the watershed must have been exposed, when the valleys below were still

[1] A. G. Högbom, Glaciala och petrografiska Iaktaggelser i Jemtlands Län; Sver. geol. Undersökn. Afh., ser. C, 4to, 1885, 38 pp., maps.

closed by ice, and Hansen consequently accounts for these shelves in the same way as those of the Dovrefjeld.

A good deal further to the north Svenonius has likewise found a terrace situated at a height of about 2,270 feet above the sea at the north-western end of the Sitas Jaur in Lule, Lappmarken: it looks down towards a completely open country, and Fredholm found two horizontal strand-lines at a height of about 1,700 and 1,800 feet above the sea on the Puollamt-Jåkko near the Stor Sjöfall. Svenonius adopts the same explanation for these [1].

It is scarcely necessary to add that the facts observed at the upper end of lake Torneå completely accord with these observations: there also we found that the ice, ascending towards the Atlantic Ocean, crossed the threshold of Stagenuni as it passed from the depths of the lake; and the sand ridges, obscurely alined over the barrier which closes the lake, must be regarded as representing the terraces of the Sitas Jaure.

These high-level terraces and strand-lines on the side of the mountains turned away from the Atlantic are thus in no way dependent on the height of the sea-level at the time of their formation: neither elevation nor depression of the land can be inferred from them. The origin of the terraces is to be found *in the retreat of the ice which exposed the cols on one side or the other of the valleys in descending order*: over these the lakes probably emptied themselves into the adjacent valleys. The famous parallel roads of Lochaber in Scotland similarly owe their origin to the closure of the valley by ice, as was long ago maintained by Agassiz: they correspond in height to the several cols of the surrounding hills.

Thus we cannot reasonably expect to find this group of lines at the same height in different valleys.

4. *Origin of the glint lakes of Lapland.* The movement of the inland ice contrary to the fall of the valleys characterizes, as we have seen, all that part of the Norwegian glint just considered, and in particular the whole region of the glint lakes of Lapland. Conditions which are never or scarcely ever met with in the Alps governed in this case the movement of the ice. The existing glacier tongues of the Alps move down the valleys, and they terminate almost without exception in free extremities. Where narrows occur at the end of a glacier they generally take the form of gorges excavated by the glacier river, like the ravine of the Möll in front of the termination of the Pasterze, and probably also the gorge of the Massa at the foot of the great Aletsch glacier. At present they either contain no ice at all, as is the case with the Pasterze, or they exercise no important influence on the movements of the glacier. Even the narrows and obstacles which do sometimes occur within the course

[1] Svenonius, Geol. Fören. Stockh. Förh., Sitzung vom 10. April 1885, VII, p. 608, and note in 1886, VIII, pp. 56, 57.

of the Alpine glaciers can scarcely be compared with the portals of the glint.

For this reason it is scarcely worth while to apply conclusions drawn from the action of the free ice-streams of the Alps to those of the inland ice of Norway. The better plan, it seems to me, is to start from the general principle that ice moves like a viscous fluid, and to consider how fluid bodies behave when subject to deflexion or when they meet with some check in their progress. We know that glaciers move faster in the middle than at the sides, faster on the convex than on the concave side of a bend, and the rate of flow of the whole mass is accelerated by a narrowing of the transverse section of the flow. Every river obeys the same laws; it attempts to maintain a constant transverse section, and at the same time to establish a regular longitudinal profile, that is, a uniform fall which is on the whole that of a flat parabola. It is only exceptionally and over closely circumscribed areas that a river works down below the normal line of its fall, and produces a hollow or pit which is known as a pot-hole or colk.

Colks may be distinguished into *swirl colks* (Wirbelkolke) and *scape colks* (Staukolke)[1].

Swirl colks are formed when the encounter of two currents sets the water rotating with a screw-like movement which bores downwards. As a rule they owe their existence to temporary causes, and fill up as soon as these cease to act: sounding in a whirlpool is difficult to carry out and uncertain in its results, so that I am not in a position to illustrate the formation of swirl colks in rivers by numerical estimates of any value. Colks of this kind are doubtless seldom produced by the glaciers of the Alps, or only on a small scale; on the other hand, they appear to be frequently formed by the great flows which proceed from the ice-mass of Greenland. The 'grydedale' which Kornerup has described in the Sermilik fjord and its tributary Alangordlia (lat. 63° 30′ to 63° 40′ N.) are great polished caldrons hollowed out in the solid rock, and though this observer does not regard them as 'giants' kettles' ground out by the ice, this is simply on account of their extraordinary size. They occur on the lee side of the mountains, which were once completely buried up by the ice-sheet, and appear to have always been open towards the fjord or valley through which a great ice-stream moved. Their form is that of a rotation paraboloid with a vertical axis[2]. These characters are such as would be produced by the rotatory boring out of a pot-hole. *Grydedale are swirl colks.*

[1] 'Stow' in the Anglo-Saxon sense of 'to hinder' might have been used as an imperfect equivalent of the German 'Stau,' but since the immediate cause of the formation of the pit is the escape of the accumulated water, 'scape,' the aphetic form of 'escape,' seemed preferable; 'colk' is a genuine English word, originally meaning a 'hole.'—Note by Editor.

[2] A. Kornerup, Geologiske Iagtaggelser fra Vestkysten af Grönland (62° 15′–64° 15′ n. Br.); Meddelelser om Grönland, 1879, I, p. 106 et seq.

Scape colks are produced by a constriction of the water channel. The efforts which have been made in the course of the last few years to regulate the course of some parts of the Danube and the Rhone have led to the necessity of shutting off branches of one or other of these rivers, or even the main stream itself, in order to force its waters into a new channel. The construction of works for this purpose is beset with difficulties. In proportion as the transverse section of the stream is made narrower it deepens its channel, and if the bottom cannot be rendered secure, either by sinking great blocks of stone, or in some other way so as to provide a solid overfall weir, the colk increases in size: and then it often happens that human endeavour is unable to cope with the stream. Above the dam the water rises; through the opening not yet completely closed it rushes with irresistible velocity, and strives continually to deepen the channel; its movement is directed from the dammed up waters downwards, like a fall over a weir; and it hollows out of its bed an elongated basin, of which the deepest part occurs below the dam. This basin is the scape colk. When the dam is completely closed then the deepest part of the colk lies below the dam in the now amputated part of the river. When the stream succeeds in breaking through the consolidated bottom we may see it tearing out heavy blocks of stone, carrying them into the depths of the colk, driving them upwards over its further slope to deposit them below the colk over the shoals in a wide semicircular mound, and sometimes at a higher level than the bottom from which they were torn.

The engineers, Messrs. Fänner and Taussig, were so kind as to furnish me with some instances of colk formation in the Danube, and they informed me that in every case their labours had been carried on uninterruptedly and with the closest watchfulness, so that the stream was never allowed time to complete its colk. I now give some of these examples.

When the ancient bed of the Danube was closed at Weidenhaufen below Vienna it was necessary to work without securing the bottom; as soon as the opening had been diminished to 45 meters, the waters showed a rise of 0·95 meter, and under this additional head the stream had already produced a colk 18 meters deep, the normal depth of the river being 3 meters; in other words, it had sunk a hole 15 meters deep.

At Fischamend a training wall, through which a branch of the Danube had flowed without hindrance by an aperture of 162 meters, was closed in 1869. The depth of the colk increased in consequence from 3 meters to 14 meters, and reached the Tertiary clay beneath the alluvial sediments.

The dyke of Elend is on the right bank of the regulated part of the Danube, and cuts off obliquely an ancient branch which proceeds from it to the right. When after much difficulty the dyke had been closed, the difference in the water level on the two sides of the dam amounted to 1·10 meters; the colk below it was 11·3 meters deep, the normal depth of the

river being 2·5 meters: a number of great blocks of stone, which had been sunk for the purpose of closing the dyke, lay 60 to 80 meters below it, that is beyond the colk, arranged in semicircles in the shallower parts of the river.

The case of the Neu-Haufen dyke below Vienna (Fig. 35) affords another example.

Of the works constructed to close the Alt-Rhein near Mannheim an interesting account has been given by Honsell. About a third part of the total volume of the water flowed away by the Alt-Rhein, which it was necessary to close. After all preparations had been made the work began on March 1, 1866, with the securing of the bottom. On April 13 the dyke, after much labour, was finished, and the difference in the level of the water above and below it amounted to 43 inches. Two days after its completion a subsidence of the crown of the dam was observed; the work had been undermined, and in a few hours the river had made an opening 50 feet broad and 15 feet deep, through which it poured with a roar like thunder. When, after fresh efforts, this breach was closed it was found that a colk had been scoured out to a maximum depth, so far as it could be ascertained after the outburst, of at least 60 feet.

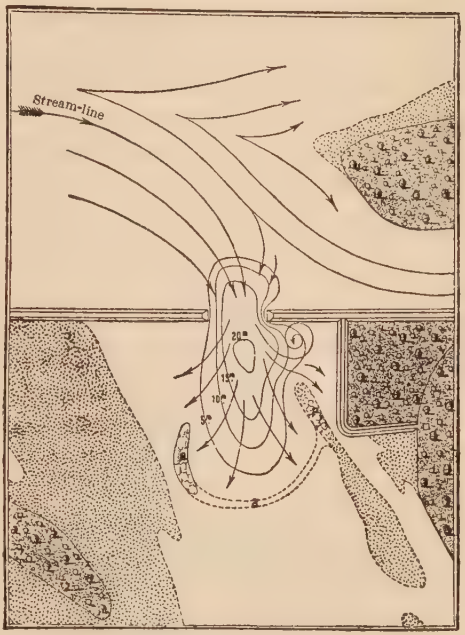


FIG. 35. *Closure of the Neu-Haufen dyke, Schüttau.* Regulation of the Danube below Vienna, 1882–1883. After a sketch by Herr Baurath Taussig.
a, a, a Horseshoe-like mound of large blocks of stone, torn from the foundation of the dam and swept along out of the colk. The mound is lowest in the middle owing to the activity of the current.

During the regulation of the Rhine in the grand duchy of Baden colks were also observed, some of which had a depth of 30 meters [1].

It is true that all the colks we have enumerated were excavated in loose alluvial soil or clay; nevertheless they show that running water, when its transverse section is compressed, has great power to scoop out and

[1] M. Honsell, Die Correction der Mündung des Neckars in den Rhein, Allg. Bauzeitung, 1871, XXXVI, pp. 383–422, maps, in particular p. 401, pl. 67, figs. i and iv; by the same, Die Correction des Ober-Rhein, Beiträge zur Hydrographie des Grossh. Baden, 4to, Carlsruhe, 1885, 3. Heft, p. 46.

deepen its bed, and there can be little doubt that given sufficient time the effect produced in a few weeks or days in loose ground would also be produced in the solid rock. All the facts indicate that the inland ice of Greenland possesses a similar power.

Jensen and Kornerup have given us a detailed description of the rocky peaks, known as Jensen's nunataks and Dalager's nunataks, which rise out of the ice above the isblink of Frederikshaab[1]. The former are the summits of a mountain ridge, which is opposed like a dam to the movement of the ice as it proceeds to the south-west. Immediately below these peaks the level of the ice is 4,230 feet, and at some little distance above them 5,000 feet. The ice thus swells up behind the dam to the extent of several hundred feet. A small part of the ice flows between the nunataks, and the altered character of its surface reveals an increased velocity. The greater part moves around the nunataks to north-west and south-east. On the south-west side, that is on the lee side of the ridge, we see moraines disposed in great crescentic arcs, standing in the midst of the inland ice. The arcs are convex downwards or in the same direction as the movement of the upper ice-stream, and they serve to define its margin. They consist of blocks of olivine diabase, such as is not known anywhere in the neighbourhood, and are no doubt derived from the ground moraine. At this spot, where the ice must possess an enormous thickness, *the effect of the dam is so great that the ground moraine is carried up from the bottom to the surface and spread out in an arc, like the blocks of stone below the dykes of the Danube.* But where, so to speak, the dead point of the movement occurs, on the lee side behind the central nunatak, there lies a circular lake 800 feet in diameter, 4000 feet above the sea, but 600 to 800 feet lower than the surface of the ice; and this Kornerup compares to a 'grydedal,' that is to a swirl colk.

FIG. 36. *Dalager's Nunataks* (after Jensen and Kornerup). Compare Fig. 37, p. 358.

The ice is dammed back in a similar manner at Dalager's nunataks; here it forces its way between these rocky masses; in front of each of the ice-streams the ground moraine is extruded in great horseshoe-shaped curves, running from one nunatak to the other (Fig. 36).

The acceleration of the current in the portals between the nunataks, the carrying up of the ground moraine from a great depth, and the formation

[1] J. A. D. Jensen, Expeditionen til Syd-Grönland i 1878; Meddelelser om Grönland, 1879, I, pp. 17–76; Kornerup, tom. cit., pp. 115, 128 et passim.

of a whirl on the opposite side of the ridge agree so completely with what we have observed in the case of running water, that we may safely affirm we have here before us similar effects produced by similar causes. Running water would produce a whirlpool and a swirl colk on the lee side, and we may even assume that at the bottom of the ice below the lake the requisite conditions exist for the formation of a grydedal. The upward movement of the ground moraine corresponds with the carrying up of blocks of stone from the secured bottom of a dam pass to the lower end of a scape colk, and thus we may fairly assume that scape colks are produced by the ice at corresponding points in its bed.

Helland, as a result of his observations in Greenland, has emphatically maintained the glacial origin of the lakes and fjords of Scandinavia; but he has based his explanations of these local excavations, not on the constriction of the transverse section of flow, indicated by the mountains themselves, but rather on the increased velocity due to the entrance of a secondary glacier into a main valley. This factor may be of great importance elsewhere, but in the lakes of Lapland it never, or at least, so far as I am acquainted with them, only very exceptionally, exercises any influence [1].

Let us return to the glint of Lapland. We have seen that it forms a high wall, the basset edges of the Palaeozoic table-land. It is interrupted by a number of portals, in which lie the elongated glint lakes of Lapland, at right angles to the rampart, so that its trace cuts through the largest of them. Through these passages the ice entered Norway. Many of their pylons were, for some time at least, submerged beneath the ice, as is proved by the red granite on the summit of the Store Jerta. But just as at Serimlik the striations at the bottom follow the direction of the fjord, while on the summits of the surrounding mountains they diverge like a fan [2], so at the time when the ice was at its thickest the portals below determined the direction of its deepest flow. Before the glacial period valleys existed, which extended from Norway through the portals towards the gulf of Bothnia. Högskar Elv, Anavandene, Gievne Jaure, fragments of the original valley system, have preserved their ancient fall up to the present day. In all these valleys the ice forced its way upwards. Each of the portals determined a mighty constriction of the flow, and at many of them the conditions were realized for the formation of a colk. Below the dam, where the colk should be, lies a lake. The ice has driven back the glint and destroyed parts of it, but so great was the resistance it offered that the ancient valleys were worn down and ground out into long deep lake basins. It was not the threshold of Stagenuni, at the upper end of lake Torneå,

[1] A. Helland, Om Dannelsen af Fjordene, Fjorddalen, Indsöerne og Havbankerne; Öfvers. K. Vet.-Akad. Förh. Stockholm, 1875, No. 4, p. 25.

[2] Kornerup, tom. cit., p. 109.

which determined the formation of the lake, but the glint which strikes straight across its middle. How otherwise shall we explain the disappearance of the block of flat-bedded rock which corresponded with the breadth of the lake? How many parallel trough-faults should we have to assume to explain the form of these lakes? And why should the glint line run right across them? The portals of inferior size and simpler structure, such as those of Tjoalma Vagge, show clearly enough that we have before us a phenomenon of pure erosion.

The glint lakes of Lapland are scape colks.

5. *Ancient strand-lines of the fjords.* In the Norwegian fjords both terraces and true seter occur. Their horizontality is extremely striking. Sometimes these lines are so sharply drawn and accompanied by such very regular terraces that their geometrical severity obtrudes itself on the eye and disturbs our enjoyment of the manifold variety of the landscape.

The accounts in our textbooks generally give a very schematic representation of these features, and explain them as the result of an oscillation of the ground, scarcely comprehensible in the face of such extreme regularity.

The much debated oscillations of the Baltic at the present day then readily come to be regarded as the continuation of the ancient oscillations of Norway. This theory receives its death-blow by the very first visit paid to one of the northern fjords; near Bodö, at Tromsö, and many other localities close to the sea, we may observe a selvage of light yellow marine sands, at a height of 30, or at most 40, feet above the strand; thousands of marine shells of existing species occur in it. This differs completely both in colour and character from the sediment of the terraces, as well as by the presence of included shells; and there can be no doubt it is of more recent age. It is the 'post-glacial' sand of Scandinavian geologists, and shows that in these fjords the conditions which now obtain are not those which existed during the formation of the terraces.

In those northern fjords which I had an opportunity of visiting, three groups of recent deposits occur.

The first consists of shell-bearing beds, which reach a height of +150 to 170 feet, and are regarded by some, Pettersen for instance, as possibly interglacial. I have not had an opportunity of examining them myself.

The second group includes the sediments of the terraces; only towards their base, as in the valley of the Maals Elv, are beds of blue clay present; all the rest is sand and gravel and small pebbles, in the midst of which a block of larger size may be seen here and there. No shells are to be seen, at least not in the upper terraces; the colour is grey or brownish grey, and the bedding, as far as it can be recognized, is oblique, suggesting rather the action of a rapid river than the sea. We have already mentioned the presence of small pieces of wood and fragments of Swedish granite in one of

the terraces of the Bals fjord (II, p. 333). These are precisely the characters usually presented by alluvial land in the valleys of mountain ranges. The glacial or fluvio-glacial origin of these accumulations is indicated by a number of facts to which we shall refer later.

The third and most recent group includes the post-glacial shelly sands of the coast already mentioned.

On the Christiania fjord, Kjerulf distinguishes older shell beds which extend up to 200 feet. It would thus seem as though the sea-level reached here a greater height than in the north. The occurrence of arctic shells up to 540 feet would indicate a sea-level of +600 feet, which would correspond to the highest terraces of the Christiania fjord [1]. Sweden does not enter into consideration here: a continuous ice-sheet once extended over the whole of Sweden together with the gulf of Bothnia and Finland, and flowed not only towards the Norwegian valleys but far over Denmark, a large part of Germany, and Russia. This was first maintained by Otto Torell, and has been confirmed by numerous later observations [2].

In the first place it must not be forgotten that both in the interior of Norway and high up in the mountains, terraces and seter have been met with which present precisely the same characters as the terraces of the fjords; and they were formed as we have shown during the retreat of the ice. We must further bear in mind that the terraces of the fjords and the accompanying steps in the rock are older than the post-glacial marine sands.

The horizontality of the seter has been contested. Bravais, who spent the winter of 1838–9 at Bossekop at the upper end of the Alten fjord, thought he recognized two particularly well-marked lines extending from this place to Hammerfest, and the measurements which he made of the lines at six points gave the following results in meters:—

	I	II	III	IV	V	VI
Upper line	67·4	56·5	51·8	49·6	42·65	28·6
Lower line	27·7	24·5	20·5	18·3	16·60	14·1
Difference of level .	39·7	32·0	31·3	31·3	26·05	14·5

From this Bravais concluded that the upper line had originally been horizontal, and had then been tilted to the extent given above in the difference of the level; hereupon the second line had been formed, also horizontal; and then both had been brought into the slanting position which now characterizes them [3].

[1] T. Kjerulf, Die Geologie des südlichen und mittleren Norwegen, German translation by A. Gurlt, Bonn, 1880, pp. 2–23.

[2] Otto Torell, Undersökningar öfver Istiden; Öfvers. K. Vet.-Akad. Förh. Stockholm, 1872, XXIX, 10, pp. 25–66, and 1873, XXX, 1, pp. 47–64.

[3] Rapport sur un Mémoire de M. A. Bravais, relatif aux lignes d'ancien niveau de la mer dans le Finmark, Compt. rend., 1842, XV, p. 838; also C. Martins, Du Spitzberg au

These observations were regarded in France, Germany, and England as a confirmation of the elevation theory; but among Scandinavian geologists they did not find equal recognition. The distance from Kaa fjord in the most southerly part of the Alten fjord (point I) to Hammerfest (point VI) amounts to 90 kilometers; Talvig (point II) lies on the western side of the Alten fjord, Leris fjord (point III) about 35 kilometers to the north-north-east, on the eastern side of Vargsund, the continuation of the Alten fjord. But since numerous horizons are indicated in this region, either by terraces or seter, and since in the Kaa fjord (point I) alone Sexe recognized as many as nine horizons between a height of 200 feet and the sea-level, there is absolutely no proof that the lines measured by Bravais belong in reality to the same two horizons [1].

It will not now surprise us to find that Mohn, as the result of numerous measurements made in the same fjord, was able to distinguish five groups of horizontal lines instead of the two divergent and not horizontal lines of Bravais; these groups occur at heights of 186, 152, 128·5, 89·5, and 73·5 feet, or 58·3, 47·7, 40·3, 28, and 23 meters [2].

A still more exhaustive account has been given by Herr Pettersen as the result of observations, extending over many years, made in the adjacent fjords of the Tromsö stift. He arrived at the conclusion that towards the upper end of the fjords, or as we recede from the sea, fragments of seter occur at an increasing height: there has not, however, been an ascent of one and the same system of seter from the sea towards the interior, but the seter occur in completely independent horizontal fragments, arranged *like a flight of steps* at heights continually increasing from the coast inland. It looks as though the conditions necessary for the formation of these lines were as a rule realized at an earlier date in the inner channels of the sound than on the coast [3].

The restriction of the highest lines to the upper end of the fjords is

Sahara, Paris, 1866, pp. 127–136. In his report on Bravais' observations E. de Beaumont (tom. cit., p. 840) opposes the hypothesis of a temporary closure by ice, because, in addition to a number of other difficulties, the surface of a glacier is not constant enough to hold up water at a fixed level. On the contrary, he is led by Bravais' observations to suppose that a fracture or flexure of the crust occurs near Rastabynaes, where there is a marked change in the inclination of the lines to one another. In the same report Biot points out the possibility of changes in the local value of gravity (p. 846).

[1] S. A. Sexe, Om nogle gamle Strandlinier; Arch. Math. Naturvid., 1876, I, p. 17, map.

[2] H. Mohn, Bidrag til Kundskaben om gamle Strandlinier i Norge; Nyt Mag. Naturvid., 1877, XXII, p. 41 et seq.

[3] K. Pettersen, Terrasser og gamle Strandlinier, Tromsö Mus. Aarsh., 1880, III, pp. 34, 36, 52; German translation by R. Lehmann, Zeitschr. Nat., Halle, 1880, LIII, pp. 820, 821, 837. The particularly long stretches of lines occurring at Viken (101 feet), Sandviken (113 feet), and Grepstad (123 feet) on the south side of the island of Kvalö in the Malangen fjord were described by Pettersen as examples of the ladder-like succession of lines. The abrupt breaking off of the several examples of lines in the Alten fjord is also discussed by Sexe, tom. cit., p. 13 et seq.

universal: the seter of Trondhjem furnishing a rare exception, to be discussed later. It is a general rule also that the coast of the islands which looks towards the open sea is deficient in these features, and indeed that high-level strand-lines scarcely ever occur on a coast facing the open sea. These lines are almost exclusively confined to the inner sounds, the much ramified arms of the sea behind the neighbouring islands, where they chiefly occur in narrow creeks; and these facts, combined with the step-like succession of higher and higher lines as we proceed towards the interior, lead us to inquire whether the terraces and seter by the sea may not have been formed in the same way as those on the high mountains.

We shall soon encounter other evidence which will leave little doubt as to this fact.

Kjerulf, whose masterly investigations extend over seven degrees of latitude and whose opinion is of the greatest weight, maintains that lines so sharply defined as those which may be seen on the coast of Norway can only have been produced by intermittent and comparatively rapid movements of the land. The same opinion had previously been expressed by Keilhau. The mode of occurrence of most of the great terraces he regards as sufficient by itself to show that they represent ancient deltas; the succession of the terraces, however, shows that *the elevation was not uniform but intermittent* [1].

This theory of intermittent elevation of the land has been opposed by Sexe, on the ground that *the height and number of the lines in the several fjords, even indeed in the several arms of the same fjord, are not constant,* and that in general on the coasts of the open sea and at great distances from the mouths of existing rivers, terraces have not been observed. In the several lateral valleys of the Hardanger fjord, Sexe remarks that the number of steps is very variable; in the Odda valley five steps are present, in the Tyssedal two, in Kinsarvik five, in the Oyfjord two, and in Graven four. Thus in the Odda, five of these sudden movements must have occurred, which produced stages at heights of 293, 94, 80, 43, and 12 feet; in the Tyssedal not far off, only two, which produced stages at heights of 253 and 115 feet. But such a supposition is inadmissible [2].

The want of uniformity in the terraces of neighbouring valleys has been emphasized still more strongly by Gumaelius. This observer has collected all the measurements of strand-lines and terraces in the region of the Norwegian coast published up to 1880, and has tabulated all the figures

[1] Kjerulf, Die Geologie des südlichen und mittleren Norwegen; German edition, p. 12 et passim. Bravais also assumes spasmodic elevations which he believes to have been more powerful in the interior than on the coast, but Kjerulf is of opinion that 'no inclined plane can be constructed from the lie of the terraces.'

[2] S. A. Sexe, On the Rise of Land in Scandinavia; Univ. Progr. Christiania, 1st Sem. 1872.

in successive groups of 10 feet. As a result we find that between 10 and 610 feet there is not a single group which does not include at least one of the measurements. As regards local peculiarities the following comes out. From the southern point of Norway to Jaederen no terrace is visible below 90 feet; thence to Trondhjem every decade from 19 to 509 feet is represented; the highest terraces lie between 570 and 579 feet. In Hardanger fjord they do not extend beyond a height of 390 to 399 feet. In the Sogne fjord all the measurements with two exceptions lie between 130 and 490 feet[1].

Passing from south and central Norway to the fjords of the north we find that in Tromsö stift and Altenfjord only lower horizons are represented, and a height of 220 feet is scarcely ever exceeded. The only general result to be obtained from these facts is that in the south the terraces and seter below a level of 90 feet appear to be absent; in the north those above a level of 220 feet.

But this great diversity in height is manifest not only in a tabular summary; it occurs also within the individual fjords. Gumaelius, among many other examples, gives the following: between the Eidfjord and the Eidfjord Vand in the Hardinger, a fine terrace may be seen on one side of the valley at a height of 360 feet, while on the other side five terraces occur between heights of 10 and 300 feet. Such great local differences could not fail to raise doubts as to the marine origin of these features. Gumaelius expresses his scepticism in the most explicit terms.

Somewhat different from the results obtained by the Norwegian geologists are those to which *Hugh Miller* was led by a study of the neighbourhood of Trondhjem. Between the sea-level and a height of 350 feet this observer distinguished not less than thirty-three to thirty-four terraces, chiefly cut in clay and situated almost without exception in sheltered places. Between a height of 350 and 580 feet he observed nine to ten terraces; the highest lines are the two seter cut in the rock above Ilsvike near Trondhjem, which will be discussed presently.

Hugh Miller regarded all the terraces as post-glacial, since the two highest seter are cut in rock which has been rounded by ice; but since the marine remains, which are known here up to a height of 380 feet, present arctic characters, the water at the time of the high-level terraces must still have been glacial. If intermittent elevations really occurred they must have been more numerous than is generally supposed; it is also doubtful, considering the great number of terraces which occur here, whether all have been preserved, or whether many may not have been effaced by storms or other destructive agents. The smaller steps resemble the lines

[1] O. Gumaelius, Några reseanteekningar från Norge: II. Rullstensgrus, terrasser och nutida bildningar af bergartsspillor; Geol. Fören. Stockh. Förh., 1880–1881, V, pp. 175–207.

which may be seen at high tides, even when there is no periodicity of any kind in the sinking of the water level [1].

It must be observed that Hugh Miller applies this last remark to only the smaller and lower terraces. I have carefully examined the two great lines above Ilsviken which were first described by Kjerulf. They occur one above the other, are about one kilometer in length, and are cut partly in schist, partly in a green granite. According to Sejersted their heights are respectively 161·1 and 177·8 meters [2]. The lower line is the more sharply defined, and presents the characters of a typical seter.

They run along a moderately steep slope, covered by low bushes and isolated trees. At its foot lies a small alluvial plain, and on this stands the town of Trondhjem; to the left is a part of the fjord, and to the right, that is towards the interior, alluvial deposits of great thickness, forming regular terraces.

A few shallow water-courses run down the slope to the plain, and are separated by broad flat ridges. The cutting back of the rock has proceeded further on the projecting ridges than in the furrows, where it is slight or next to nothing, and as a result we have a horizontal causeway which varies in breadth, attaining its maximum on the ridges, where it is sometimes as much as 30 meters across; on the mountain side it is bounded by a steep but not very high cliff. The cliff shows no trace of striation, but presents a splintered and broken-up appearance. This shelf in the rock has certainly not been produced during either a rise or fall of the strand-line, but at a level which must have remained stationary at precisely this height for a long time. The excavating action must have been rapidly interrupted, otherwise the broad horizontal causeway would not have been so perfectly preserved. So far we may accept Kjerulf's view, but not his supposition that the cause of the rapid interruption was intermittent elevation. These remarks do not apply to the lower terraces, which are unaccompanied by seter, and cut in soft clay.

A peculiar association of terraces and glacial formations was described many years ago by Codrington, and subsequently in great detail by Helland and Holmström [3]. The facts are as follows:—

Ascending from the sea we first cross a series of terraces; the upper-

[1] Hugh Miller, Some Results of a detailed Survey of the old Coast-Lines near Trondhjem, Norway; Brit. Assoc. 1885; Nature, October 8, 1885, p. 555.

[2] J. Sejersted, in R. Lehmann, Neue Beiträge zur Kenntniss der ehemaligen Strandlinien im anstehenden Gestein in Norwegen, Zeitschr. Nat., Halle, 1881, LIV, pp. 60, 68. Kjerulf was the first to describe this line; Om Skuringsmærker, &c., part II, Univ. Progr. Christiania, 2nd Sem. 1875, p. 91. He gives as the heights 462 and 510 feet; Mohn obtained 160·7 and 178·5 meters.

[3] T. Codrington, On the probably glacial Origin of some Norwegian Lakes, Quart. Journ. Geol. Soc., 1860, XVI, pp. 345–347; A. Helland, Om Beliggenheden af Moræner og Terrasser foran mange Indsöer, Öfvers. K. Vet. Akad. Förh., 1875, XXXII, pp. 53–82; also Quart. Journ. Geol. Soc., 1877, XXXIII, pp. 165–172; L. Holmström, Om moräner och terrasser, Öfvers. K. Vet. Akad. Förh., 1879, No. 2, pp. 5–47, pl.

most of these, sometimes forming a broad plain, ends towards the interior against a terminal moraine, which stretches across the whole valley, and so to speak crowns the terraces; we will speak of these then as *crowned terraces*. On the other side of the moraine comes a lake, recognizable as a true rock basin; its surface stands above the sea-level, its bed frequently descends far below. In some cases additional terraces are to be seen beyond the lake on the landward side; these must be regarded as its marginal terraces.

The lake is thus dammed across by the terminal moraine, and the mass of alluvial land in which the crowned terraces are cut stands in most intimate relation with the moraine. Sexe pointed out many years ago that the alluvium must have been transported into its present position during the existence of the glacier, for it could not otherwise have crossed the site of the moraine and lake.

Helland emphasizes the fact that this relation of the terminal moraine to the terraces is repeated in nearly fifty of the largest lakes of Norway, and in the most typical instances which he cites from the west of the country, as in the Hardanger, the Sogne, and Nord fjords, the height of these terraces scarcely ever exceeds 100 meters. The case of the Horningdals Vand, Nordfjord, is remarkable on account of the extremely great depth of the dammed up lake; its surface stands at +54 meters and its depth is 486 meters; it therefore descends to −432 meters.

The moraine is not always distinctly marked; the lake then appears to end directly against the uppermost terrace; this is the case which has been discussed in connexion with the Sagel Vand, Bals fjord (II, p. 333). Pettersen has described a peculiar example in Kvænangen, where two small lakes, one behind the other, are cut off from the sea by a similar barrier. Kornerup has given a sketch of the south Kangerdluarsuk in Greenland, showing five successive terraces crowned by a terminal moraine at a height of 400 feet.

I have not visited the Hardanger fjord, but it would appear to present some very instructive features. Helland states that the lake Gravens Vand is separated at its head from the sea by alluvial land with terraces at 9, 16·5, and 41 meters. In the detritus of the middle terrace trunks of trees, cones of Conifers, and also hazel nuts occur. The post-glacial shell beds extend as far up as the highest terrace, i. e. 41 meters. This recalls the carbonized wood of the terrace of the Bals fjord, and we must wait for further evidence to decide whether these plant remains, and with them the alluvial deposits, belong to an interglacial episode or not. The cutting out of the terrace itself, judging from its height, which is identical with that of the shell beds, may have commenced in post-glacial times[1].

[1] K. Pettersen, Kvænangen; et Bidrag til Besvarelse af Spörgsmaalet om Fjorddannelsen, Tromsö Mus. Aarsh., 1881, IV, pp. 1–36, map; Kornerup, Meddelelser om Grönland, 1881, II, p. 186; Helland, Om en Stigning af Landet ved Hardangerfjord i en geol. særdel. nær Tid, Geol. Fören. Stockh. Förh., II, 1875, pp. 120–125.

In all these cases the end of the glacier occupied the hollows now filled by lakes, at the time the delta was formed; and the upper surface of this, often of considerable extent, stands to the lake in much the same relation as the recent alluvial plains, raised and levelled by winding glacial brooks, stand to some of the lakes in the Alps, as for instance the plain of Gschlöss below the Schlattenkees of the Venediger. The accumulation of the glacier silt must be distinguished from the formation of the terraces, since the latter are subsequently cut out of the former, even as the lines in the cliffs have been cut out of the hard rock.

Sexe and Gumaelius, reasoning from local differences in the height of the terraces, arrived at different explanations, which agree, however, in regarding the terraces as due to deposition in stages, the result of variations in the quantity of transported material, or in the rate of melting of the ice; but theories of this nature will not explain the existence of lines cut in the rocks, and I can scarcely believe that terraces of deposition would present such sharp outlines; we have seen also on the Sagel Vand that the irregular stratification of the terraces is more steeply inclined than their slopes.

In certain fjords between lat. 68° 50′ and 70° N. another kind of connexion between the terraces and the events attendant on the close of the glacial period, no less remarkable than the preceding, has been recognized by Pettersen. In this region the ice has distributed over the land thousands of erratics derived from a characteristic red granite in Sweden, and, as we have already mentioned, Pettersen has met with erratics of this rock on the slopes of the Store Ala in Bardo up to 3,200 feet, and on the Mauken towards the Tag Vand up to 2,500 feet. In the immediate neighbourhood of the sea the height at which these blocks of red granite occur suddenly diminishes. It certainly appears as if the glaciers bearing with them these erratics had pushed forwards, probably at a time when the retreat of the ice was arrested, against the moraine which closed the fresh-water lake in the Salangen and also, under similar conditions, over the Sagel Vand towards Bals fjord, but in these localities the boulders have already sunk to a level of some few hundreds of feet. On the coasts of the fjords themselves they are scattered up to a horizontal limit, which according to existing observations does not extend above 200 feet in Salangen, 160 in Malangen, and only 120 to 130 feet in Bals fjord. Pettersen believes that these erratics were distributed by drift ice, at a time when the ice cap was melting. The upper limit of the erratics in the fjords coincides with the upper limit of the terraces[1].

Here we may remark that the great and lofty islands off the coast, as

[1] K. Pettersen, Det nordlige Norge under den glaciale og postglaciale Tid, III Bidrag; XI, Granitisk Flytblokkeström udefter Maalselv, Bardo og Salangsdal; Tromsö Mus. Aarsh., 1885, VII, pp. 23–38.

well as the most westerly parts of the peninsula itself, which in places, as in the Lyngen fjord, still bears glaciers, were certainly not free from ice during the glacial epoch. On the contrary they were the centres of independent glacier systems, which behaved towards the invading inland ice of Sweden just as the existing local glaciers of the western part of south Greenland do towards the ice of the east. Holm has shown that on the west side from cape Farewell down to about lat. 60° 30′ N. the land rises in high mountains from which glaciers radiate out in all directions as in the mountain groups of the Alps; in the east, however, the heights do not exceed 3,000 feet, and a snow-covered ice-sheet, through which isolated peaks protrude, mantles all the land; but even at the present day the glaciers are increasing in size, and it seems as though they would ultimately unite to form a continuous sheet. Similarly in Norway, Pettersen has recognized that the Troms Tind, 3,970 feet high, situated not far from the west coast, was passed by a mighty glacier tongue which once stretched across the existing sound to the island of Tromsö, and this it covered with rocks derived from the Troms Tind [1].

In the fjords of the Tromsö stift a certain subordination and connexion of phenomena may be recognized. We see a mighty mass of ice coming from Sweden and advancing towards the Atlantic through the portals and over the pylons of the glint, and the red granite blocks lie more than 3,000 feet above the existing level of the sea. In the region of the existing fjords, this ice-sheet appears to have encountered the ice-flows produced by a local glaciation, which proceeded from the heights and islands of the west coast. The marine deposits observed by Pettersen in Lavangen at a height of 150 feet and on Tromsö at 170 feet were, he thought, possibly interglacial, as may well be the case, for they must be more recent than the first great glaciation and older than the terraces situated at a lower level.

After the first advance of the ice, the glaciers, although they did not attain their previous dimensions, moved forwards a second time, pushing their frontal moraines towards the upper end of the Salangen fjord, the Bals fjord, and many other arms of the sea, where they deposited their detritus. Then followed the formation of the terraces, which were contemporaneous with the second glacial episode or the latter part of it. Finally the ice disappeared; at a height of +30 to 40 feet the post-glacial shelly sands were deposited on the coast; the deepening of the valleys by running water commenced and still continues, as well as the formation of new river terraces.

Lastly, we must mention that in the northern fjords continuous beds of

[1] G. F. Holm, Geografiske Undersögelse af Grönlands sydligste Del, Meddelelser om Grönland, 1883, VI, p. 174 et seq.; K. Pettersen, Det nordlige Norge, &c., IX, Tromsdalen, Tromsö Mus. Aarsh., 1885, VII, pp. 5–20.

pumice are sometimes met with: in Vargas, Bedemar describes their occurrence at Jupwik and on the coast of Kwalö; Keilhau was acquainted with beds of this kind; Roberts records pumice at Hammerfest, 60 to 80 feet above the sea; Pettersen found it near Tromsö, often at a height of 30 or 40 feet; near Bodö, in making an excavation numerous fragments of pumice associated with *Cardium edule* and *Littorina littorea* are said to have been met with at a height of 150 feet. Instances of pumice occurring in the higher beds of the interior parts of the fjords are not known to me. These waifs can only have been washed in from the open sea [1].

As a result of these very various observations, we recognize the following peculiarities as characteristic of these formations: the association of terraces with sharply-cut seter; the horizontality of all the lines; the step-like succession of lines at levels, continually increasing in altitude towards the head of the fjord; the restriction of the highest lines to the head of the fjord or its larger lateral valleys; the want of correspondence between the height of the lines in adjacent fjords, or in different parts of one and the same fjord; the occurrence, by no means rare, of a lake in the glacier bed, closed at its lower end by a moraine, which, towards the sea, crowns terraced alluvial land; and the coincidence in some of the fjords of the highest lines with the upper limit of the erratic blocks, which have been distributed by drift ice. Finally, the rule appears to hold that in the extreme south of Norway the lower horizons are not represented, while the upper horizons are similarly absent in the north.

Several of these characters—such, for instance, as the step-like succession of the lines at continually increasing altitude towards the head of the fjord, and the absence of higher lines towards its mouth, a rule to which there is scarcely an exception; or, again, the breadth of the seter, which points to a rapid change in the relative level of land and water; and, finally, the inequality of the heights—cannot by any means be reconciled with what we know of the action of the sea between tide levels. On the other hand, there are a number of facts which point to the influence of ice.

Under these circumstances we must seek information in those localities where similar conditions prevail at the present day. The existing ice-sheet of Greenland presents itself along the west coast as the remains of a once much more extensive mass which advanced a long way towards Baffin bay, filling all the straits in front of the fjords and overwhelming a great part of the adjacent islands. The largest of the existing glaciers are but the relics of the far larger ice-streams of the past. According to Steenstrup's observations, the glacier of Jakobshavn once filled the bay of Disco; that of Torsukatak the Vaigat strait; the glacier in the fjords

[1] Vargas Bedemar, Reise nach dem hohen Norden, 8vo, Frankfurt a. M., 1819, II, pp. 99, 289; by the same, Arktis II, Arch. Math. Naturvid., 1881, p. 476.

of Umanak and Karat carried an immense mass of ice beyond Ubekjendt Eiland; the gneiss blocks of the mainland were dragged along and scattered over the basalt table mountains which form the peninsula and islands of the coast. Near the settlement of Nugsuak, at the extremity of the peninsula of the same name, which projects into the sea towards the west, the direction of the ancient striation runs from north to south, and this fact, together with the immense quantity of foreign boulders on Hare island and on the west side of Disco, appears to indicate, as Steenstrup points out, that Baffin bay itself was once filled with ice[1]. Similar evidence of a former far greater extension of the ice is afforded by numerous localities along the coast.

Terraces and shell-bearing sand occur in Greenland. It is true that in the glaciated region which extends from cape Farewell to lat. 60° 30′ N. neither terraces nor shells are mentioned by Holm: on the other hand, between lat. 60° 45′ to 61° 15′ N., Steenstrup observed terraces up to a height of 150 feet, but no shells, except at two places 10 to 15 feet above high water[2]. From lat. 62° 15′ to 64° 15′ N., Jensen and Kornerup observed terraces up to 612 feet, and marine shells up to 35 feet, the latter only at one place on the coast. Further, shells of *Mytilus edulis* and *Mya truncata* were encountered at a height of 35 feet on the shore of an inland lake near Björne sound. Kornerup adds that the terraces in Ameragdla (338 feet) and Ilivertalik (322 feet) have doubtless been formed by the sea, since they occur in an exposed position; but that it is scarcely likely the sea reached the level of the single high terrace on the Björne sound (612 feet); a valley may frequently be barred across by a moraine, and in the basin so closed alluvial flats may be formed simulating a marine terrace. Kornerup's account contains a particularly instructive description of the effect of the tides on the mighty mass of sand and clay which the great Frederickshaab glacier bears with it into the sea; the planing down of the material in the tidal zone is repeated twice daily. Between lat. 66° 55′ and 68° 30′ N., the same observer met with terraces up to a height of 380 feet, but shells only in a single locality at a height of 20 feet. Finally, between lat. 69° and 72° 30° N., Hammer and Steenstrup found terraces up to 478 feet, and shells up to 190 feet[3]. The shells in this case were observed at a single locality only, at Pagtorfik (Umanak), where they lie in stratified basaltic

[1] K. J. V. Steenstrup, Bidrag til Kjendskab til de geognostiske og geografiske Forhold i en Del af Nord-Grönland; Meddelelser om Grönland, 1883, IV, pp. 213, 220.

[2] G. F. Holm, Geografisk Undersögelse af Grönlands sydligste Del, op. cit., 1883, VI, pp. 149–192; K. J. V. Steenstrup, Bemærkninger til et geognostik Oversigtskaart over en Del af Julianehaab's Distrikt, op. cit., 1881, II, pp. 39–40.

[3] A. Kornerup, Geologiske Iagttagelser fra Vestkysten af Grönland (62° 15′–64° 15′ n. Br.), op. cit., 1879, I, pp. 94–102; by the same, Geologiske Iagttagelser fra Vestkysten af Grönland (66° 15′–68° 15′ n. Br.), op. cit., 1881, II, pp. 181–189; K. J. V. Steenstrup, Bidrag til Kjendskab, &c., pp. 227–236.

sand, and, according to all accounts, Nordenskiöld's in particular, they would appear to date from a somewhat early period[1]. At Kugsuak (Disco fjord), Steenstrup observed valves of *Mya truncata* in a terrace 172 feet high, and in the Nord fjord shells are found on both sides of the fjord at a height of 70 to 80 feet. The other beds lie only 20 feet above the sea, and the most recent formation, just above high water, is represented by some beds with *Mytilus edulis* in the Disco fjord. Steenstrup discusses the question whether the movement of the strand-line took place continuously or intermittently, and considers the latter more probable, since the terraces are so sharply defined; he adds, however, that one and the same terrace may present in one place a single uniform slope, and in another a succession of subordinate steps, so that local influences must have made themselves felt.

From the foregoing it would appear that at various localities along the coast as far as Disco, and between 20 and 35 feet above high water, shelly sands occur in a position similar to that occupied by the post-glacial sand on the west coast of Norway, and that the marine shells met with at a greater height have hitherto been found only in the most northerly of these regions. The terraces reach far greater heights. At the same time we must observe that the mollusca and Echinoids of the present day always avoid fresh or muddy water in the neighbourhood of a glacier; their presence indicates the absence of ice in the neighbourhood.

We may now compare the two great glaciers of Frederikshaab and Jakobshavn.

For the former, we will again follow the accounts of Jensen and Kornerup[2]. The end of the glacier, of great breadth and traversed by radiating crevasses, advances towards the sea with a convex front, known as the Frederikshaabs isblink[3]; the flat land in front of it, formed of material which it has itself transported, measures about 8·5 kilometers in breadth. The isblink itself is the splayed-out end of a stream of inland ice which flows from Jensen's nunataks towards the south-west. In its progress this ice-stream dams up on its south side a fresh-water lake, the Tasersuak, which lies at a height of +940 feet, and is covered by icebergs given off at both ends of the calving glacier. The Greenlanders have a tradition that the Tasersuak was once a fjord, and that before the ice closed it, it could be entered even by the big boats used by women. This indeed may well have been the case, although the traveller Dalager is said to have crossed the lake as early as 1751. The lake communicates by

[1] A. E. Nordenskiöld, Redogörelse för en expeditionen till Grönland, år 1870; Öfvers. K. Vet. Akad. Förh. Stockholm, 1870, No. 10, p. 1018.

[2] J. A. D. Jensen, Indlandsisen öst for Frederikshaabs Isblink, 1878; Meddelelser om Grönland, 1879, I, map C.

[3] The Danish spelling has been retained, since English navigators attach a different meaning to the word 'ice-blink.' (Note by the Editor.)

a canal in the ice with another and much smaller lake, situated at a height of 640 feet, and from this a river flows into the upper part of Tiningnertok, a deep fjord filled with fresh water, and completely separated from the sea by the silting up due to the isblink.

Similar phenomena occur on the north side of the ice-stream. Two fairly important fresh-water lakes are formed by a T-shaped extrusion of the ice; their height above the sea is not known; like Tasersuak they are covered with fragments of floating ice. Below them lies the Majorarisat fjord; in 1878 its communication with the sea was almost cut off, and

Fig. 37. *Frederikshaabs Isblink* (after Hammer).

only maintained by a powerful current which undermines the inland ice at its mouth. Majorarisat on the north corresponds with Tiningnertok on the south side.

Tasersuak is 33·8 kilometers in length, and 5·6 kilometers in breadth; here, we might suppose, the incessant drifting of the ice and the changes of temperature should afford opportunity for the formation of a line or shelf in the rock. If the lake were then to be suddenly emptied, a horizontal shelf would remain, which would be interpreted as the sign of a spasmodic movement. We thus see that in Tasersuak a surface of water exists at a level of 940 feet; below it there is a small sheet of water at a level of 640 feet; on the north side another sheet, also above the level

of the sea, at a height not yet determined, or there may even be two sheets of water at different heights, that is the two lakes above Majorarisat; then follow the silted-up fjords and the open sea. It is certain that the ice also carries sand and mud into the inland lakes; if at any time these should empty themselves even in part, then the conditions would be realized for the carving out of terraces. *Thus from* 940 *feet down to the sea-level, there occur at different levels all the conditions preliminary to the formation of horizontal lines and steps, without the intervention of oscillations either of land or sea.*

The vast variety of the conditions created in this way will appear still more clearly if we consider another example, the glacier fjord of Jakobshavn.

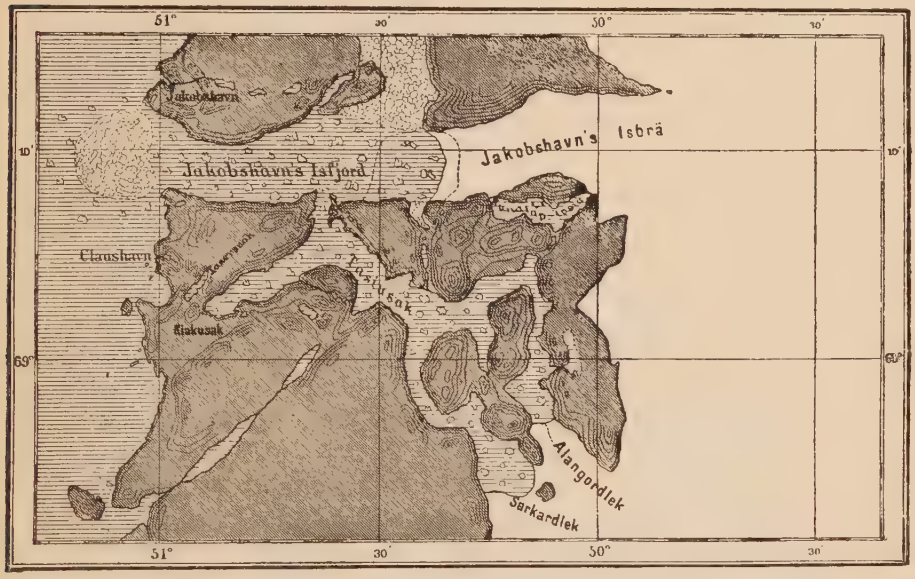


FIG. 38. *Jakobshavns Isfjord* (after Hammer). On the same scale as Fig. 37.

This was first described by Rink; it was on the great glacier, which here reaches the sea, that Helland made his observations in 1875, when he demonstrated, for the first time, the extraordinarily rapid movement of this outflow from the inland ice; the most detailed description has been given by Hammer[1].

The calving of the glacier is always in progress; the height of the vertical ice front amounts to about 200 feet, but towards the interior the upper surface of the glacier soon rises to over 1,000 feet. Its mean velocity, as estimated by Hammer, may be taken as 50 feet a day; in the

[1] R. R. J. Hammer, Undersögelser ved Jakobshavns Isfjord og närmeste Omegn, Vinteren 1879–1880; Meddelelser om Grönland, 1883, IV, pp. 1–68, maps.

illustration the line in the sea represents its termination as it was seen by Rink in 1850; Helland in 1875 found the glacier calving in the middle of the little bay on the south side; the line drawn on the ice represents its state according to Hammer in the autumn of 1879, and the map shows it as it was in March, 1880: it had receded 4·2 kilometers since 1850. At present the south side of the glacier closes the great fresh-water lake of Nunatap-tasia. The surface of this lake stands at 165 feet, and towards the west, where Hammer bored through the ice, 5·6 inches thick, which covered its surface, its bottom sinks to about 100 feet below the sea-level. If the glacier should continue its retreat a little longer, then Nunatap-tasia would be emptied and again become part of the fjord. If, on the other hand, it should advance beyond its position in 1850, then it would soon reach the narrow mouth of the great and much ramified fjord of Tasiusak, which even now is generally filled with icebergs; the outer part of Jakobshavn's ice-fjord likewise is so cumbered with ice, as to be unnavigable for the greater part of the year, and as a consequence Tasiusak is generally reached by a portage situated south of Claushavn. If Tasiusak were closed, and if, at the same time, the slowly moving glacier arms of Alangordlek, which only exceptionally bears moraines, and of Sarkardlek, which contains 387 grammes of sediment per cubic meter of water, were cut off from the sea, then conditions would be realized here having an obvious resemblance to those which determined many of the terraces of the Norwegian coast. Below the termination of Alangordlek crowned terraces might arise. The height of the water level in the whole region of the Tasiusak would then depend on the height of the lowest portage not covered by ice. The portage of Claushavn, mentioned above, bears the lake of Tasersuak, which lies in a hollow at a height of 102 feet. East of this lake the road leads over a ridge, only 207 feet high, to the fjord of Kiakusak, which is a branch of the Tasiusak. *At the upper end of the Kiakusak, and thus in the region of the Tasiusak, terraces actually occur up to a height of* 200 *feet.* If the isblink of Jakobshavn were to advance, then conditions would be again realized for the formation of similar terraces at the same height, and without the least alteration in the position of the strand-line[1].

A word may be added as to the Nunatap-tasia. It is now a reservoir for the water produced by the melting of the glacier. Hammer has shown

[1] When Rink, and afterwards Helland, visited the south side of the fjord of Jakobshavn glacier, they thought they were in the bay of Tivsarigssok, a little bay on this coast, which, according to the Greenlanders, contains seals, the flesh of which tastes like reindeer meat. Hammer, however, believes that the 'seals' bay,' Tivsarigssok, lies further inland and was quite icebound, and that Rink and Helland were in the bay Kangerdlukasik. I mention this as illustrating the variation to which the glaciers in these secondary bays are subject; A. Helland, Om de Isfyldte Fjorde og de glaciale Dannelser i Nordgrönland, Arch. Math. Naturvid. Kristiania, 1876, I, p. 74, note, and Hammer, mem. cit.

by investigations carried on during the period of severest cold, that fresh water flows from the glacier the whole winter through, so that at certain times it lies on the frozen surface of the lake. It is in autumn that the water level is highest; in March it is about three feet lower; on April 1, 1880, the temperature of the air was found to be $-20{\cdot}3°$, and that of the ice, six inches below the surface, $-19{\cdot}6°$. Thus slight oscillations of the water level occur, and very great changes in the temperature to which the rock is exposed; such circumstances, as may be easily supposed, must be particularly favourable to the production of a permanent mark in the rock.

Whether an advance of the Jakobshavn glacier would produce similar phenomena by closing the fjord of Sikui-juitsok on its north side is doubtful, for, according to Hammer, this fjord is already so overburdened by ice that it would then, in all probability, become completely filled.

If the outflows of the inland ice were again to advance, as they did in the past, through Karrat, Umanak, Weigat, Disco fjord and elsewhere, into the sea, then behind Ubekjendt Eiland, Disco, and in many other places, opportunity would occur for the formation of lines and terraces on a much greater scale, and at heights and in situations of almost infinite variety. *For this reason all the seter and the great majority of terraces in the fjords of western Norway must be regarded as monuments of the retreating ice, and not as evidence of oscillation of the sea-level, and still less of oscillation of the solid land.*

No doubt negative displacement of the strand-line did occur during and after the period of the greatest extension of the ice in Norway: the repeated occurrence of marine shells above the existing sea-level is a proof of this. It is equally certain that at present the Norwegian rivers are still engaged in modifying their valleys, and are capable of creating new terraces. The seter and terraces in the fjords, however, are generally characterized by special features, which are met with neither in marine nor fluviatile formations, but are precisely those which would result from the conditions associated with the movement of the glacier tongues of Greenland.

The terraces and seter on the slopes of the Dovrefjeld and in Lapland beyond the Swedish watershed are therefore, despite their elevated position, all members of one and the same series of phenomena, to which the terraces and seter in the fjords also belong. The step-like succession of fragments of horizontal lines which appear towards the head of a fjord at progressively higher horizons, is thus simply a proof that the fjord has been completely barred across by ice: at first there was a little lake at a high level, then as the ice receded, a larger lake at a lower level was produced either by the exposure of a lower lying col or ejde, or owing to the behaviour of the ice itself; and so on, again and again.

We may now distinguish between the various types of closure, such as the occlusion of a valley on the retreat of an ice-stream which had previously moved towards the mountains (Dovrefjeld, Sitas-Jaur), or by the passage across its mouth of an ice-stream, which may also have rested simply as a mass of ice on the sea bottom, as was certainly the case in most of the fjords; or the same process may be repeated on a smaller scale in transverse valleys, either by simple closure (Lochaber, Rofn, Marjälen, Arandu in Basha) or double closure (Tasersuak on the glacier of Frederikshaab, Nunatap-tasia on that of Jakobshavn); or twin lakes with a T-shaped barrier may arise (above Majorarisat); but everywhere in the valleys of the Alps, the Himálaya, Scotland, and Norway, and in the fjords of Norway and Greenland, we find essentially the same features which have been left behind by the varying movement of the ice. All these types of closure, and with them the crowned terraces, are only secondary modifications of a phenomenon frequently met with in severely glaciated lands, which indeed, as Nordenskiöld pointed out in 1870, constitutes one of their most marked characteristics, that is, the presence of a fresh-water lake at the meeting-place of the ice and rock [1].

During the glacial period, and even after it, the strand in Norway stood higher than at present; the terraces met with in very open bays, as for instance in Christiania fjord, which is essentially different from the narrow fjords of the north, may indeed be genuine vestiges of a sea-coast, like the terraces of western Patagonia, which also occupy an open situation; but the seter are not so, nor are many of the terraces of the west coast of Norway, especially those of considerable altitude. The crowned terraces are cut in the débris cones of valleys through which glaciers once moved, for a time at least. The sheet of water which cut these terraces may have been the open sea or a confined lake.

Those fjords of the north which I had an opportunity of examining myself resemble in every respect submerged valleys. The great lakes of upper Italy, Lago Maggiore, lakes Como and Garda, produce the same impression. They are closed by alluvial land, like so many small lakes at the heads of fjords, and since moraines stand at their exits the plain of upper Italy recalls in a certain sense the crowned terraces in front of the Norwegian lakes. Strapff compares the fragments of high-level lines in the Tessin valleys with those of Trondhjem, and they may be of similar origin. Omboni's description of the Etsch glacier squeezing its way below Trient through a narrow valley, turning out of its course into the Sarca

[1] Nordenskiöld, Redogörelse, p. 1007, fig. 2. Sudden eruptions of masses of water are also known in Greenland, e. g. Kleinschmidt, Meddelelser om Grönland, II, p. 132; the two fjords Tangnera and Mamak, which intersect the island Christian IV (lat. 60° N.), are only separated from each other by a heap of débris 1,000 paces broad, probably a landslip; Holm, op. cit., IV, p. 166.

valley, and then uniting with the Sarca glacier to enter the fjord, now represented by the lake of Garda, brings to mind many a region in Norway [1].

In Norway, it is true, the ice ascended the valleys towards the mountains, first, in a broad mass, then along the wall of glint; next, issuing with increased velocity, it deepened the valleys beyond the original portals of the glint, until finally it reached the sea beyond the ancient watershed. The deep hollows of the ejde afford another feature peculiar to the north.

[1] F. M. Stapff, Strandbilder, Zeitschr. deutsch. geol. Ges., 1882, XXXIV, p. 53; G. Omboni, Delle antiche morene vicine ad Arco nel Trentino, Atti R. Ist. Veneto, 1876, 5ª ser., II, pp. 457–467.

CHAPTER IX

THE TEMPLE OF SERAPIS NEAR PUZZUOLI

The north-west coast of Italy. Situation of the temple of Serapis in the Phlegraean crater. The temple up to the year 1538. The eruption of 1538. Excavation of the temple and its present condition. Various attempts at explanation. Volcanic phenomena.

The north-west outline of Italy has lost by recent silting up much of that variety which resulted from the destruction of the folded mountains. Some of the ruins still rise from the sea between Corsica and the coast of the mainland as independent rocky islands; some, such as Monte Argentario, are connected with the land by recent sediments, others by marine deposits of somewhat greater age and situated at a greater height; others again are offshoots from the main trunk of the Apennines and orographically continuous with it.

Among the post-Tertiary sediments of this region two formations may be readily distinguished. A recent marine deposit forms horizontal plains of considerable extent, about 15 to 20 meters above the existing sea, but it also occurs on the slopes, where it attains a greater height; and we may assign to it the marine *panchina* of Tuscany. It is generally crowded with shells identical in kind with those of the existing sea, but it also contains a small number of extinct species, among them *Cyprina islandica*, one of the northern immigrants[1]. Lotti observed this *panchina* in the island of Elba at a height of from 20 to 25 meters, but in one locality it rises to about 200 meters; in the island of Giglio its height is 15 meters; in the island of Cerboli, to the east of Elba, 30 meters; on the coast of Leghorn, 15 to 25 meters, but in some places as much as 69 meters, and near Campiglia 165 meters. T. Fuchs describes this deposit as forming an extensive gently undulating country which, over the whole distance from Orbetello to Montalto, scarcely ever rises above 20 meters. Hollande and Reusch mention its occurrence in Corsica at a height of from 15 to 20 meters[2]. This marine formation, as is shown by the various patches still adherent to the slopes, corresponds to a fairly high level of the strand.

[1] C. de Stefani, Sedimenti sottomarini dell' epoca post pliocenica in Italia; Boll. R. Com. Geol. Ital., 1876, VII, pp. 272-289.

[2] B. Lotti, Calcari marini quaternari lungo la costa dei monti Livornesi, Boll. R. Com. Geol. Ital., 1885, 2ª ser., VI, pp. 54-56, 253; T. Fuchs, Reisenotizen aus Italien, Verh. k. k. geol. Reichs., 1874, p. 223; Hollande, Géologie de la Corse, Ann. sci. géol., 1877, IX, p. 103; also Bull. Soc. geol. de Fr., 1875-1876, 3ᵉ sér., IV, pp. 86-91, and H. Reusch, op. cit., 1882, 3ᵉ sér., XI, pp. 53-67.

It is evidently of prehistoric age, and, except in those places where confusion has been produced by kitchen middens, as in Corsica, it is always sharply separated from the younger group, which comprises the low plain formed by the most recent alluvium, together with the marshes, lagoons, and spits of the present day.

This last group of deposits, still in process of formation, alone concerns us now.

To gain a closer acquaintance with it, let us leave the Maremma railway at the Orbetello station; the road to the town runs along a narrow tongue of land; at the lower end of this the town is situated, and in the middle the Stagno d'Orbetello; continuing past it, a connexion, part dam, part bridge, brings us finally to the Trias rauchwacke which forms the east side of Monte Argentario. This mountain mass, as has been shown by Cocchi, is an anticlinal, trending in the same direction as the Apennines, and cut through by a strike fault[1]. From its wooded slopes we overlook the Stagno. On our left towards the north it is separated from the open sea by a long sand-bar, the Tombolo del Pino, which is continued in a wide gentle curve from Monte Argentario to the rocky peak of Talamonaccio. Another sand-bar similar to the first, but shorter, the Feniglia, bounds the Stagno on the south; it unites the Argentario with the rock which bears the cyclopean ruins of Cosa. These narrow ridges of sand run like spun threads from one fragment of the Apennines to the other; no unequal movement of the earth's crust is conceivable, whether by tilting, arching, or otherwise, which would not destroy this fragile structure.

Let us first examine the northern bar.

Impressed by the uninterrupted activity of the constructive processes and the regularity of the bars and spits, Repetti long ago maintained that neither elevation nor subsidence of the strand had occurred along this stretch of coast. Nor are proofs in support of this assertion lacking. In the north, where the Tombolo del Pino is narrowest, before it reaches the rock of Talamonaccio, it is traversed for about 7 kilometers by the Via Aurelia Nova, which originally led to Pisa: this road was continued further to the north in the year 114 B.C. by Aemilius Scaurus, and afterwards called the Via Aemilia. Thus no important change has occurred here for twenty centuries.

Spits or bars one after the other engirdle the coast of Tuscany, and prove step by step as we proceed to the north the impossibility of any unequal movement of the ground. In the neighbourhood of Campiglia the old Roman road again follows the outer bar close to the sea. The little harbour of Vada, the landing-place for Volterra, owes its existence to two dry banks which project in front of it, and Repetti refers to the fact

[1] I. Cocchi, Note geologiche sopra Cosa, Orbetello e Monte Argentario; Boll. R. Com. Geol. Ital., 1870, I, pp. 277–309.

that these same banks were seen by Rutilius Numatianus when he landed at Vada in 415 or 420 A.D.[1]

Space would fail were I to attempt to enumerate the various documents, chiefly ecclesiastical deeds of gift, which from the beginning of the ninth century onwards enable us to establish the existence in those early times of many of the inland waters or salt-pans which are still to be seen along this coast. A change of outline is of course chiefly noticeable in the neighbourhood of the larger rivers. There the new alluvial land advances to the sea; successive series of bars or spits accompany the river in its progress, but I cannot discover from the accounts before me any movement of the strand-line, either in a positive or negative direction. In fact, the advance of the rivers does not proceed gradually; on the contrary, while the destructive work of the sea accomplished at the point of the projecting alluvial land is fairly uniform, except during storms, the constructive work of the river takes place chiefly during high water, and is practically arrested at low tide.

The thorough-going investigations of Stefani into the historical records of the advance of the Arno and the Serchio show that Pisa was 3·7 kilometers distant from the sea in Strabo's time, that is, at the beginning of our era, while at present the distance amounts to 12·36 kilometers; but no change in the level of the strand can be deduced from this[2].

We might raise the question as to why such a considerable growth of alluvial land should have taken place in so many localities in historical times, and often, indeed, it would seem as though the process had not been so extensive in earlier periods; but I believe the cause is to be found in an interference with the course of nature, which everywhere accompanies civilization, namely, the regulation of the rivers and the deforestation of the hills. Importance has also been attached to the fact that in some of the lagoons parts of the Roman road are submerged, but Stefani justly points out that it is in precisely these regions that the stone foundations of the railway so frequently sink in: the Via Aurelia was also constructed as an *agger*, that is, a stone causeway[3].

Let us return to Monte Argentario, and thence turn our attention to the south.

The ridge which closes the Stagno d'Orbetello on the south, the

[1] E. Repetti, Colpo d' occhio sulle principali vicende fisiche accadute prima e dopo il mille lungo il littorale toscano; in his Dizionario geografico fisico-storico della Toscana, 8vo, Firenze, II, 1835, pp. 704–711; V, 1843, pp. 709–713 et passim; Art. Vada, V, pp. 616–618.

[2] C. de Stefani, Geologia del Monte Pisano, Mem. R. Com. Geol. Ital., 1877, III, pp. 73–87; for the legends connected with the course of the Serchio see his Auser, Arno, e Serchio in Pisa, Cosmos, ed. G. Cora, 1884–1885, VIII, p. 289 et seq.

[3] This is the case in the Lago Scarlino; Savi has several times mentioned this example.

Feniglia, rests at its landward end against the rock which bears the ruins of Cosa, the ancient city of the Volsci. On the Feniglia, Cocchi found the remains of the ancient Etruscan road, which led from Cosa to the port of Hercules on the east side of Monte Argentario.

The rock of Cosa itself has been cut through on its south-east side by human agency, and the breach is now called the 'Bagno della Duchessa'; but, as was recognized by Movizzo and Cocchi, it is in fact a channel made in ancient times to drain the marshes lying behind it, the Padule della Tagliata and the Lago di Burano, which are separated from the sea by a bar more than 20 kilometers long. This bar is a part of the gently curved ridge of alluvial coast-land which leads to Civita Vecchia. The marshes and the bar thus existed in ancient times, and the strand then stood at the same level as at present, for the same breach still serves for a drain, just as it did two thousand years ago[1].

As regards the land formed by the Tiber, the case is the same as that of the Arno. When we consider for how great a distance this river follows the northern slopes of the great tuff cones which contain the crater lakes (Maare) of Bolseno, Vico, and Bracciano, we shall readily perceive what great effects must follow the deforestation of this region, and shall have no difficulty in tracing the yellow colour of this river to its source. Ponzi has collected all the information bearing on the growth of the delta since the year 633 B.C. (when Ancus Martius founded Ostia on one of the alluvial spits) down to the present day; and from this he concludes that an elevation of the land has taken place. I cannot, however, perceive any signs of this; an elevation would have made itself felt in Rome by a deepening of the river bed, but no such deepening has occurred[2].

The Grotta della Capre, which occurs in the limestone of the promontory of Circe, affords some very instructive evidence. In the cave we find, according to Issel, first a zone of Lithodomus borings at a height of 7 to 8 meters, and a second zone at 4 to 5 meters. The bottom of the cave is filled with stratified material which forms a level floor at a height of 6 or 6·5 meters,

[1] Cocchi, Note sopra Cosa, &c., pp. 291, 281, 282.

[2] (1) From the foundation of Ostia (633 B.C.) to the addition by Trajan of a reservoir to the harbour of Claudius (110 A.D.), 743 years, advance 950 meters; (2) up to the time when Pius V built his tower (in 1569), 1459 years, 1750 meters; (3) up to the tower of Alexander VII (built 1662), 93 years, 550 meters; up to the tower of Clemens XIV (Torre Clementina, built 1773), 111 years, 450 meters; up to the year 1874, 101 years, 400 meters; Ponzi, Boll. Soc. Geogr. Ital., 1875, XII, p. 523; and by the same, Il Tevere ed il suo delta, Riv. Maritt., 1876, IX, pp. 1-40, pl. This observer, who has added so considerably to our knowledge of Rome, even believed he could deduce from the level of the water-gauge at Ripetta that the ground of Rome had gradually and imperceptibly risen to the extent of 0·971 meter between the years 1821 and 1871; but such a considerable alteration would certainly have been accompanied by a deepening of the river bed; Ponzi, Sui lavori del Tevere e sulle variate condizioni del suolo romano, Trans. Accad. Lync., 1880, 3ª ser., IV, pp. 203-208.

and so covers up the lower zone of borings. This infilling material consists first of a layer of loose stones, among them pebbles; this rests on a sheet of stalagmite, and beneath the stalagmite lies red earth, in which the remains of mammals, fragments of charcoal, and implements of the stone age are found[1].

Thus not only the cave itself is older than the stone age, but also both zones of borings—the lower, which lies at a height of 4 to 5 meters, being the oldest. Consequently this zone can by no means be regarded as contemporaneous with the borings occurring at a similar height in the temple of Serapis at Puzzuoli, and just as little can we assign to the historic period the Lithodomus borings which are found at many other localities on this coast, or not at least till we possess further evidence. Such zones are known in the rock of Talamonia, Monte Argentario, and cape Circe. A zone at Gaëta which attains a height of 5 or 6 meters has frequently been described, most recently by Bianchini[2].

We can now understand why Strabo complained of the absence of harbours at Volterra (v. 2. 6), Circeji (v. 3. 6), and elsewhere on the west coast of Italy. Over the whole of this region we are presented with immediate evidence that the existing state of things has remained unchanged for centuries, as in the case of the ancient drain of Cosa: on the other hand, positive evidence of any alteration within the historic period is wholly wanting. The Roman remains which are met with here and there beneath the sea outside the alluvial bars prove nothing in this respect. They are foundation walls built into the sea for baths, landing-places, and other purposes.

The more clearly all the indications in this region witness to a long-continued persistence of existing conditions, the more important it becomes to examine into the evidence presented by the classic example of the temple of Serapis at Puzzuoli.

1. *The situation of the temple at Serapis.* The borings of marine shells, which present themselves in a broad horizontal band on the pillars of the temple of Serapis at Puzzuoli, are adduced by numerous observers, and in most of our textbooks, particularly in Lyell's 'Principles of Geology,' as a proof of the repeated elevation and subsidence of the solid land. Nevertheless, Antonio Niccolini, the most competent authority on this subject, whose observations have been made on the spot and extend over many decades, has always maintained in his numerous contributions to this question, that the land has remained stationary; that which has changed is the level of the sea.

The importance which has been given to this case, the conclusions to which it has led, and the extreme complexity of the attendant circum-

[1] A. Issel, Le oscillazioni lente del suolo o bradisismi, pp. 205–210.

[2] E. Bianchini, Delle oscillazioni del suolo sulle coste di Gaeta; Riv. Maritt., 1882, XV, pp. 389–402.

A. Haase, Prague, Lithographer to the Imp. & Roy. court.

stances render a detailed discussion necessary. I shall first consider the peculiar situation of the temple, and then pass in review all the accounts known to me concerning the history of the locality, both before and after the eruption of Monte Nuovo in the year 1538. The last part of the chapter deals with the theoretical conclusions which various observers have drawn from the facts[1].

In the Phlegraean fields that radiate arrangement of the craters which distinguishes the Lipari isles is absent. All the Phlegraean craters on the mainland, with the exception of Monte di Procida and the outermost parts of the promontory of Misena, belong, as Roth rightly observes, to a single large and very flat conical mountain mass (I, I, Plate II); and this is clearly shown on the hypsometric map published by the Royal General Staff of Italy[2].

In the south-east, on the east side of cape Posilippo, the foot of this great tuff cone is washed by the sea, and consequently steep; the steep slope is continued through the Chiaja and below fort Saint Elmo into the city of Naples; then it flattens out to the north of the city. Towards the north, in the neighbourhood of Marano, the outer border of the volcano gradually disappears beneath the plain; towards the west it is indicated by the lagoons of Licola and Fusaro, and from the southernmost part of the latter, the Aqua morte now lying dry, a depression runs to the south-east towards the Mare morte of Misena, which clearly separates the Phlegraean cone from Monte di Procida. Indeed, this depression, which runs transversely across the south part of the promontory of Baiae, is of no small importance. On both sides of it the hills rise with a gentle slope; in the north-east the outer border of the Phlegraean cone, and in the south-west the slopes of Monte di Procida. At the same time, both hilly ranges break off abruptly on the averted side, the first towards the bay of Puzzuoli, the second towards the open sea. Monte di Procida, characterized by the presence of leucitophyre, must be regarded as a fragment of the neighbouring island of Procida, as was long ago shown by Arcangelo Scacchi in his excellent description of the neighbourhood[3].

The south part of the Phlegraean cone lies beneath the sea. Its diameter from north to south cannot therefore be determined, but from

[1] In the course of many years I have succeeded in collecting the original writings on this subject, which in many cases were published as mere fly-sheets, and are therefore extremely rare; but I have failed to obtain several of the most important works of a later date. Some of these have been placed at my disposal by the University Library of Pisa, and others by the National Library of Naples, through the kind intervention of Signor Commendatore Meneghini.

[2] J. Roth, Der Vesuv und die Umgebung von Neapel, 8vo, Berlin, 1857, p. 485; Ordnance-map, 1 : 50,000, foglio No. 61, parte orientale, Napoli.

[3] A. Scacchi, Memorie geologiche sulla Campania; Rendic. R. Ac. Sci. Napoli, 1849, pp. 64 and 242.

east to west, or from the city of Naples to the lagoons of Cumae, it measures 18 to 20 kilometers.

To the east this cone is cut through by the grotto of Posilippo; here species of marine shells, such indeed as still exist, are found in its tuff. In the north a very large elliptical crater lake (Maare) occurs in it, precisely resembling lake Albano in the tuff mass of the Alban mountains, and of similar dimensions. This is the Piano di Quarto; the level plane within it measures 2·4 to 4·5 kilometers.

On the west side a little mass of trachyte projects from the flank of the cone and forms the rock of Cumae.

The Phlegraean cone rises with a gentle slope towards the interior, not, however, in a single circular arc like the Somma of Vesuvius, opposite the atrium, but in a number of small crescentic subsidences, following one after the other, and separated by spurs; these have often been taken for so many craters, although many of them are certainly only caldron-shaped subsidences. The result of this arrangement is that the conical surface, rising gently towards the interior, attains its greatest height where it approaches most closely to the centre, that is, on the spurs between the subsidences, namely, at the monastery of the Camaldulas (455 meters) and on Monte Barbaro (329 meters), which I am also inclined to regard as a part of the outer Phlegraean cone.

The inner fractured edge begins on the promontory of Posilippo, near the island of Nisida, and extends thence to the first crescentic subsidence near Fuorigrotta, somewhat north of the western exit from the grotto. Then follow the two great subsidences of Soccavo and Pianura, separated by the spur of Camaldula; here the 'Piperno' occurs interbedded in the tuff cone. Beyond the caldron of Pianura another spur succeeds, then we meet with smaller crescentic features, which form the slopes of the Montagna Spaccata; further on the caldron or crater of Campiglione, the 'Gaurus inanis,' is sunk into the tuff cone, then comes the lake of Avernus and the semicircular bay of Baiae.

Thus the walls of the subsidences bound an inner region, of which the longer axis, taken from Fuorigrotta to the slopes above the Lucrine lake, measures 11·5 kilometers[1].

Within this outer rim, but restricted to the eastern side, rises a second flat cone. This, starting from the low-lying foot of the rim, opposite Nisida, gently ascends at Fuorigrotta, Soccavo, and Pianura towards the centre (II, II, Pl. II), and abruptly terminates along a second fractured

[1] When L. von Buch visited the Phlegraean fields for the second time, in the company of Humboldt and Gay Lussac, he wrote: 'The Lago d'Agnano, the Quarto, Pianura, and Soccavo resemble volcanic formations just as little as Capo di Monte and Posilippo. Mere hilly surroundings are not sufficient to prove that the enclosed region is a crater. Might it not be a subsidence?'—Gesammelte Schriften, I, p. 458.

edge of similar configuration. The greater part of the second marginal fracture contributes to the circular boundary of what was once the lake of Agnano; towards the north and south respectively a smaller subsidence occurs, and the spurs north and south of the caldron of Agnano (214 and 176 meters) are again the highest points of this region. The southern spur bears the appropriate name of Monte Spina, and is distinguished by its peculiar lava. The inner region is then still more constricted, and the distance from the foot of Monte Spina to the slopes on the Lucrine lake does not exceed 7 kilometers. Within this space we see first an almost level plain (IIIa, IIIa, Pl. II), corresponding to the field of scoriae in the interior of a great crater, and above this rise the ash-cones of Astroni, Senga, and Cigliano. These have not been active in historic times (IIIb, IIIb, Pl. II).

It is only when we proceed further to the south and west that we reach the latest traces of eruptive activity, the ash-cones of the Solfatara, said to have broken out in the year 1198—though there is some doubt as to this—and Monte Nuovo, which was thrown up in the year 1538 (IV, IV, Pl. II). Around these hills, from the Solfatara to Baiae, hot springs abound. The Romans used to hollow out grottos in the tuff and fit them up as vapour baths.

In the middle of this almost extinguished hearth between the Solfatara and Monte Nuovo, is the Serapis temple of Puzzuoli. Its distance from the crater of the Solfatara is only 1,500 meters, and from the centre of Monte Nuovo 2,800 meters.

If we compare the caldron-shaped subsidences of the Phlegraean crater, such as lake Avernus or Lago d' Agnano, with the caldron-shaped subsidences of Keanakakoi and Kilauea-iki, outside the crater of Kilauea, as described by Dana, we shall find such a degree of correspondence as to suggest a similar mode of origin[1]. The Avernus caldron, measured at its upper margin, has a mean diameter of about 1,200 meters; and Kilauea-iki of about 850 to 900 meters. It is a question whether the great hollows on the slopes (Maare), such as the Piano di Quarto, might not have been produced by an invagination of the surface, consequent on a lateral reflux of the lavas towards the eruptive centre. In any case it may be assumed that the volcanos of the Phlegraean cone are seated over a common subterranean focus. There is in general a striking resemblance to the cones of the Alban mountains, and there also it is conceivable that the great crater lakes of Albano, Nemi, and Ariccia were formed solely by the invagination of the mantle after the escape of the lavas, particularly since Tucci has shown that they are simple subsidences, without any signs of independent eruptive activity. I have myself, on three several occasions, visited these 'Maare'

[1] Dana, Amer. Journ. Sci., 1887, XXXIII, pl. 1 et passim.

and examined their margins, but have sought in vain for any signs of eruptive action[1].

It is otherwise with the formation of the caldrons of the Pianura, Soccavo, Agnano, and others resembling them. They were evidently the walls of the active throat, even if not independent vents themselves. Palmeiri states that in 1779, and particularly in 1872, Vesuvius, after the eruption, fell back into itself so to speak; that is, the walls of the chimney sank into the evacuated cavity[2]. Thus great crescentic subsidences and smaller caldrons may originate around the crater, and likewise great step faults such as those which surround the crater of Kilauea.

In the bay of Naples, as on the whole coast of Italy, many traces of negative movement are to be seen. On mount Epomeo in Ischia, the younger Tertiary marine deposits attain a height of over 500 meters. It is worthy of note that as early as 1849 Scacchi propounded the inquiry whether Epomeo had been elevated along with these deposits, or whether the whole surrounding country had subsided, and he was inclined to adopt the latter alternative. On Capri zones of borings at a high level have long been known. At Anacapri, Walther observed strand-lines with Lithodomus holes at a height of about 200 meters; these are, perhaps, connected with the zones of Lithodomus borings, described by Verri and Meli, above Rome at heights of 276 and 268 meters, and assigned with great probability to the same age as the yellow marine sand of Monte Mario near Rome[3].

Nearer the sea-level such indications are not rare. To the south-west of Ischia, near the Punta dell' Imperatore, a hard breccia of pumice and trachyte, containing marine shells, rises to + 10 meters, resting upon a rock of trachyte; they have been described by Scacchi. At a height of + 8 meters and less, Walther noticed shells of Lithodomus and strand-lines on the first of the Faraglioni of Capri. At the foot of Monte Olibano (a mass of trachyte which proceeds from the Solfatara towards the sea) the following observations were made in the year 1872. Lowest of all, on the right hand lies a coarsely stratified mass of yellowish white blocks of pumice with an irregular eroded surface (*a*, Fig. 39); upon this, mantling over all the irregularities, follows stratified brown marine sand, containing crumbling shells—it extends to a height of about + 12 meters (*b*); this is succeeded by a fairly thick layer of large fragments of trachyte and scoriae (*c*, *e*),

[1] P. di Tucci, Saggio di studi geologici sui peperini del Lazio; Mem. Accad. Lync., 1879, Anno 276, ser. 3, vol. IV, pp. 357-392.

[2] Palmieri, Annali vesuviani, 1874, 2ª ser., I, p. 55.

[3] J. Walther, Studien zur Geologie des Golfes von Neapel, Zeitschr. deutsch. geol. Ges., 1886, XXXVIII, p. 304; R. Meli, Sulla zona di fori lasciati dai Litodomi pliocenici nella calcaria giurese di Fara Sabina, Boll. R. Com. Geol. Ital., 1882, 2ª ser., III, pp. 149-155. The characters of these zones of boreholes along the Italian coast are treated in a suggestive manner by A. Issel, Le oscillazioni lente del suolo o bradisismi, 8vo, Genova, 1883, pp. 99-101. Older observations in Boettger, Mittelmeer, p. 129.

with an intervening red layer (*d*); upon *e* rests the trachyte stream (*f*) from the Solfatara, and above this lie ashes, pumice, and some scoriae (*g*), possibly the products of the eruption of the Solfatara, already referred to as said to have taken place in 1198 A.D.[1]. In the trachyte a Roman aqueduct is cut; consequently the shelly sand is much older than the temple of Serapis, but at the time of its deposition the second Phlegraean cone (II, Pl. II) had already collapsed.

Scacchi describes as younger than the shell bed of the Punta dell' Imperatore in Ischia, an accumulation of sand, pumice, and shells still retaining their colour, which extends up to a height of about +20 meters. It is visible on the low cliff (evidently an ancient sea-margin) between

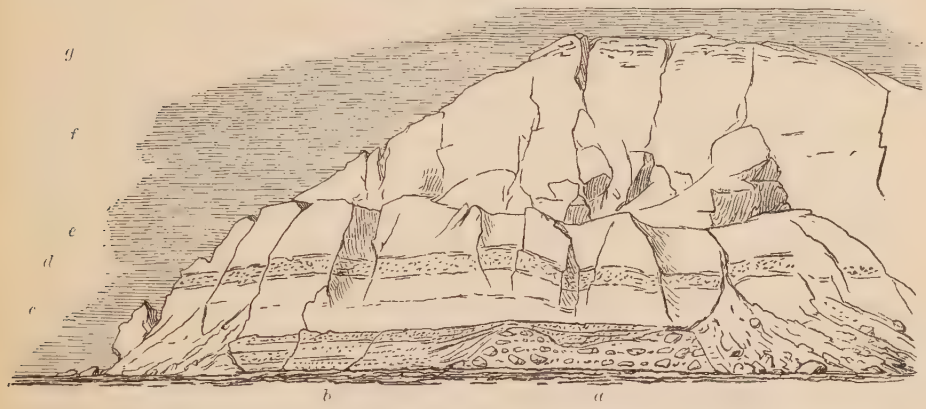


FIG. 39. *Monte Olibano, seaward face.*

a Agglomerate of pumice; *b* marine sand; *c*, *d*, *e* coarse lumps of trachyte and red layer; compact trachyte proceeding from the Solfatara; *g* recent ejectamenta.

Puzzuoli and Monte Nuovo, almost at the same height as on Ischia. Storms or seismic waves may have helped to raise these beds.

These examples of negative movement, which might be multiplied, all appear, with the exception perhaps of the last, to belong to the prehistoric period, and must be included among those abundant vestiges of high-level shore-lines which occur in the basin of the Mediterranean, and may be seen at hundreds of places between Gibraltar and the isthmus of Suez. They must be carefully distinguished from the oscillations of Puzzuoli, which belong to the historic period, and are of so wide an amplitude that if the movements had been general and uniform they would have left

[1] Guiscardi has given a drawing of this place in Atti R. Ac. Sci. Napoli, 1863, I, No. 7, fig. 3, and G. von Rath describes the shell beds in his Geognostisch-mineralogische Fragmente aus Italien, Zeitschr. deutsch. geol. Ges., 1866, XVIII, p. 614. The relation of Monte Olibano to the Solfatara is explained by the section in Scacchi, Campania, pl. i. Scacchi doubts the eruption of the Solfatara in 1198, because the crater in Strabo's time appears to have been precisely the same as at the present day.

obvious signs of their existence in neighbouring localities, and would have found a place in popular tradition; but this is not the case.

It is true that in the lower parts of the city of Naples some signs of positive movement since the Roman period may seem to exist; but the evidence afforded by baths close to the seashore, in yielding alluvial ground, covered by the rubbish of the town, is of little value. It is only when we enter the Phlegraean crater that we discover conclusive proof of oscillations within the last two thousand years. We may find it in the first place on Nisida. Niccolini states that the mole of Nisida, like the so-called 'bridge of Caligula' at Puzzuoli, rests partly on ancient piers, and that these were built when the shore-line lay at a lower level; he says also that a channel interrupted by the adjacent cliff of the Lazaretto Vecchio was originally a connecting path, and has now become a channel of the sea[1].

Within the bay there are many places where Roman constructions may be seen, which extend down to the water's edge and even beneath it. The long row of stone piers which proceeds from Puzzuoli into the sea as the bridge of Caligula—doubtless part of an ancient harbour—shows clearly that the shore is now higher than at the time the piers were erected, for the top of the stone foundation and the base of the brickwork, as well as the springers of the arches, are under water; on the other hand, some of the piers are covered with Serpulae, and bored by Lithodomus to a height of about + 3 meters. Here, therefore, true oscillation has taken place, namely, first positive and then negative movement; but it remains doubtful whether the existing submergence of the lower part of the arches is the result of an uncompleted negative phase, or the beginning of a positive phase.

These columns are only about 700 meters distant from the temple of Serapis.

The remains of the temple are situated just outside the town of Puzzuoli, towards the north-north-west, on a low and narrow plain, the *la Starza*, which stretches along the coast as far as Monte Nuovo, and borders the low cliff already mentioned. The pavement of the temple of Serapis lies somewhat below the existing sea-level. Three great columns still stand erect; the Lithodomus borings in these extend up to about + 5·3 meters. On the island side, close behind the temple, is the hot spring of the *Cantarelle*.

If we proceed from the bay of Puzzuoli past Baiae towards the west, we reach the coast of the Tyrrhenian sea. The shore is here formed by sand dunes stretching in a long and uniform curve from the west side of the promontory of Misena to Gaëta, and continued thence further north along

[1] A. Niccolini, Tavola metrica cronologica delle varie altezze tracciate dalla superficie del mare fra la costa di Amalfi ed il promontorio di Gaëta nel corso di xix secoli, 4to, Napoli, 1839, p. 26, note 3.

the edge of the marshes. This long 'lido' separates several sheets of water from the sea—the Lago del Fusaro, or the lake of Acheron, the Lago di Licola, Lago di Patria, and others. Strabo describes lake Acheron as a 'muddy expansion of the sea'; about forty years later Seneca had himself carried over the lido of Cumae to the country house of Servilius Vacca, situated near the southern end of lake Acheron: 'Like a narrow road,' says Seneca, 'the path is shut in between the lake and the sea.' Niccolini concluded, from the different description given by Strabo and Seneca, that the lido must have arisen in the brief period of four decades[1]. This conclusion is not justified by the texts; these long dams, constructed by sea and storms in the course of thousands of years, are only a continuation of the same alluvial strip which we have already followed from the mouth of the Arno to Gaëta. They show that unequal movements of extensive tracts of solid land have not occurred in this region for a very long time.

2. *The temple of Serapis up to the year* 1538. Let us now return across the promontory of Misena.

The whole littoral region, from this promontory to that of Athene (Sorrento), is called by Strabo ὁ κρατήρ. In the restricted sense which geologists now attach to this term, the bay of Puzzuoli is, as we have seen, in truth a crater. It was in the flowery fields of Puteoli, Baiae, and Misenum that, under the empire, at the expense of a subjugated world, the most sumptuous festivals were celebrated, and 'the dance in the crater' was here, within the fractured margin of the Phlegraean cone, not a metaphor but a fact. Here Cicero wrote his letters; here Octavius cut through the ancient barrier of the Lucrine lake, led the sea into the crater of Avernus, constructed locks, and created Portus Julius; here, in the heart of the volcano, between Puteoli and Baiae, Nero attempted to drown his mother in a treacherous boat; and here the elder Pliny embarked in A.D. 79, as he hastened on his way to observe the great eruption of Vesuvius. These places are therefore very frequently mentioned by Roman writers, but statements relating to the character and position of the strand are rare[2].

Almost the only important account of antiquity is contained in the Puteolanic *Lex parietis faciundi* of the year 105 B.C.[3]. This law deals with the repair of a wall on the other side of the road beyond the temple of Serapis towards the sea, and is so detailed as to leave scarcely any doubt that at that time a road lay between the temple and the strand. This

[1] A. Niccolini, Descrizione della gran Terma Puteolana volgarmente detta Tempio di Serapide, 4to, Napoli, 1845, parte geologica, p. 13 et seq.

[2] e.g. Strabo, v; Pliny, Hist. Nat. xxxi. 2; Suetonius, Aug. xvi; Dio, xlviii. 50; Horace, Odes, ii. 17; Vergil, Georgics, ii. 161 et passim; also K. Schultess, Die Nordküste des Golfes von Neapel im Alterthum, Mitth. geogr. Ges. Hamburg, 1885–1886, pp. 173–198.

[3] Quoted in Iul. Caes. Capacio, Puteolana Historia, 4to, Neapoli, MDCIIII, fol. 21–23; Niccolini, Gran Terma, pl. et passim.

would show that the strand-line then lay considerably lower than at present. The question, however, arises whether the great edifice, adorned, as the existing inscriptions tell us, with costly marbles, at the command first of Septimius Severus and then of Alexander Severus, the ruins of which are now before us, is really the same as that referred to in the *Lex parietis faciundi*, framed more than three centuries before these adornments. We shall in fact learn that beneath the pavement of the great temple which bears these inscriptions, a more deeply-buried pavement belonging to an older structure has been found. Pausanias (160 to 180 A. D., viii. 7. 3) says that near Dikaearcheia (Puteoli) hot springs well up out of the sea, and that an artificial island was created by means of dams in order to capture them for baths[1].

The noble and spacious edifice, with the remains of which we are now occupied, was, however, certainly not built below the surface of the sea. It was connected with a hot spring; this rose, as we have seen, on the inland side behind the temple, it then flowed through and supplied the baths within; in later centuries the spring attained a great reputation under the name of *le Cantarelle*; it still exists in its ancient place behind the temple.

Then followed a period of decline and devastation: for many centuries we have no information whatever. The first reference I am able to cite was discovered through the kind assistance of Professor von Mussafria and the studies of Dr. A. Goldmann. We find indeed among the documents of the sixteenth century relating to the hot springs of Puzzuoli the copy of a remarkable strophe which refers to the Cantarelle, and runs as follows:—

Inter aquas pelagi fervens aqua manat: et ipsa
Ne fluat in pontum sectile claudit opus.
Cum mare fremescit: locus oppugnatur ab undis.

Thus when these lines were written the sea extended inland beyond the temple, and a wall had been built to protect the spring. The verses are part of a long panegyric on the baths of Puteoli which was ascribed to an ancient poet, said to be Eustacius de Matera. Now Goldmann shows, by an ingenious analysis of the epilogue and by various comparisons, that the true name of the poet was Petrus de Ebulo, that the work was dedicated to Frederick II, and composed in the years 1212 to 1220.

We must consequently conclude that a higher level of the strand existed here as early as the beginning of the thirteenth century.

[1] Qualis in Euboico Baiarum litore quondam
Saxea pila cadit; magnis quam molibus ante
Constructam ponto iaciunt; sic illa ruinam
Prona trahit, penitusque vadis inlisa recumbit;
Miscent se maria, et nigrae adtolluntur arenae.
Verg., Aen. ix. 710-714.

Again there is an absence of references, and this continues until the middle of the fifteenth century.

Jorio, in his detailed treatise on the temple of Serapis, cites three legal documents of the years 1441, 1491, and 1524, which relate to transfers of property in the now-abandoned cliff, and in these the estates are described as *iuxta litus maris* or *iuxta ripam*. At that time, then, as in the thirteenth century, the Starza lay under water [1].

Three columns of the temple of Serapis were standing then as at present, but they were buried to a great depth in the débris which covered the fallen temple, and the exposed upper half of the shafts was probably washed by the waves. Villano consequently writes of the Cantarelle spring in the year 1526: 'e prima nello lito che da Puzolo ua a Trepergole che sta alo lito de lo mare doue stanno le colonne [2].'

The sea, however, must have extended beyond the temple, otherwise Petrus Aretinus would not have reproduced in 1507 the ancient verses referring to the Cantarelle in his little book on the sights of Puteoli [3].

Thus it is not correct to say that there is a complete absence of written testimony as to a higher level of the strand-line; on the contrary, we can hardly doubt that during the thirteenth century and up to the beginning of the sixteenth the Starza was submerged as far as the hot spring behind the temple of Serapis. At the same time it is highly probable that the movement took place slowly in the course of preceding centuries; at least no writer of that time, so far as I am aware, mentions this change.

On the other hand, Jorio, quoting a document preserved in the episcopal archives of Puzzuoli, mentions that on October 6, 1503, the king and queen gave to the commune of Puzzuoli a plot of ground—'che va seccando il mare intorno la terra'; and in like manner King Ferdinand gave to the town on May 23, 1511, 'quoddam Demaniale territorium mare desiccatum circa praefatam civitatem Puteolorum in continentiis eiusdem situatum.' From these expressions Niccolini concludes that the negative movement began in the sixteenth century; but this conclusion possibly rests on an error. Cumae, several times destroyed in the Middle Ages, sank at length into a resort for thieves, so that finally, in 1207, as it

[1] A. de Jorio, Ricerche sul tempio di Serapide in Puzzuoli (estratte dei Monumenti inediti di antichità e belle arti, Napoli, 1820, fasc. 1 e 2), 4to, pp. 53, 54.

[2] J. Villano, Croniche de la inclyta città di Napoli emendatissime, con li Bagni de Puzolo e Ischia; novamente ristampate (ed. Leonard. Astrinus, M.D.XXVI). Stampate in Napoli per el medesimo M. Euangelista, fol. lxxvii, b.

[3] LIBELLVS DE MIRABILIBVS CIVITATIS PVTEOLORVM, &c., Francisci Aretini. Hoc opusculū p eundē Augustinū Tyfernū cursim reuisum & auctū; Impressū est Neapoli a Sigismundo Mair Alamāno Regnante Ferdinando Aragoneo Rege. Prima Iunii. Anno a dñica natiuitate M.D.VII, fol. 7, 6. In this copy, the earliest known to me, *fertile* appears instead of the correct reading *sectile*; e.g. F. Lombardo, ΣΥΝΟΨΙΣ EORVM, QVAE De Balneis aliisq. miraculis Puteol. scripta sunt; Venet. MDLXVI, p. 37, Scholia.

appears, the Neapolitans resolved to raze the place to the ground. This was done, and from that time the civitas Puteolana extended over the devastated region of Cumae as far as the west coast. This explains, for example, the expression occurring in a diploma of Frederick's of the year 1489: 'In toto littore, seu maritima dictae Civitatis Puteolorum, usque ad flumen Patriae.' The flumen Patriae, however, lies far beyond the Lago di Licola towards the north. Thus the deeds of 1503 and 1511 refer, most probably, not to regions within the bay of Puzzuoli, but to the broad silted-up stretches of the west coast in the ancient region of Cumae, and the grounds for the hypothesis of a negative movement at this time disappear [1].

3. *The eruption of 1538.* We have now arrived at a critical episode, that is, the formation of Monte Nuovo, which occurred in the last days of the month of September, 1538. We possess four contemporaneous accounts of this event.

The first of these is by the distinguished physician and man of science, *Simone Porzio*, who then occupied the chair of philosophy at the University of Naples. It appears to have been written at the command of the Viceroy, Peter of Toledo, with the design of dispelling, by a faithful representation of the occurrence as a natural event, the illusions fostered among the people by imagination and superstition [2].

The second account was written by *Marco Antonio delli Falconi*, then in the service of Bernardo Tasso, father of the great and unhappy poet at the court of Salerno. Tasso had passed through Rome without visiting Pope Paul III, and now sent Falconi with a letter of apology. On his journey the latter witnessed the eruption [3].

The third account is contained in a letter of *Francesco del Nero*, who was then representing the court of Tuscany at Naples [4].

[1] On this point the best information is to be found in a paper printed in Naples in 1775 : Dissertazione corografico-istorica delle due antiche distrutte città Miseno e Cume. Per lo rischiarimento delle ragioni del Regio Fisco contra la Università di Puzzuoli, 4to, p. 182, &c.

[2] DE CONFLAGRATIONE Agri Puteolani, Simonis Portii, illustr. D. Petro Toledo, &c., &c. (The first edition appeared at Naples, without indication of date or place of printing, in 1538 ; the second at Florence in 1551.) Edited by L. Giustiniani, I tre rarissimi opuscoli di Simone Porzio, di Girol. Borgia e di Marcant. delli Falconi, scritti in occas. della celebr. eruzione avven. in Puzzuoli nell' ann. 1538, 8vo, Napoli, 1817, pp. 43–51. The conclusion runs: 'Haec igitur mi Maecenas scribenda duxi, ne Harioli, somniorumq. interpretes, ac vulgares Astrologi alio tragant, quae natura duce proueniunt.'

[3] DELL' INCENDIO DI POZZUOLO, MARCO ANTONIO DELLI Falconi all' Illustr. Sig. Marchesa della Padula nel MDXXXVIII. Si venne per Marco Antonio Passaro alli Ferri Vecchi ; also Giustiniani, pp. 285–330.

[4] Lettera di Francesco del Nero a Niccolò del Benino, sul terremoto di Pozzuolo, dal quale ebbe origine la Montagna Nuova, nel 1538; printed from the manuscript in Archivio storico ital., 1846, IX, pp. 93–96 ; translated by Haagen von Mathiesen, Neues Jahrb. Min., 1846, pp. 702–707, and by M. Neumayr, Der Bericht des Francesco del Nero über die Bildung des Monte Nuovo bei Neapel, op. cit., 1883, II, pp. 45–51.

The fourth and last occurs in a long poem by *Girolamo Borgia*, poet, soldier, and afterwards Bishop of Massalubrense, who made use of the opportunity to dedicate it to Pope Paul III. The poem gives a vivid picture, but is scarcely available for our purposes[1].

It is not clear at what time Simone Porzio visited the scene of the occurrence, but his description of the fugitives on the road leads us to suppose that he hurried thither in the early morning after the eruption had taken place, which happened between one and two o'clock. We know that this was so in the case of Falconi, and he mentions that the viceroy also hastened to the spot with a numerous following. On the fourth day, when the eruption was renewed, Falconi was on board ship in the bay of Puzzuoli. As for del Nero, he must have arrived at Puzzuoli some days later.

From these accounts we may educe the following:—

As early as 1488 (1458?) a violent earthquake occurred in the region and caused a great loss of life. At the beginning of the sixteenth century repeated shocks were felt. In the years 1537 and 1538 they became increasingly frequent and violent. On September 27 and 28, 1538, they succeeded each other without cessation. Then, says Porzio, the sea retreated about 200 feet, and fresh-water springs burst out. The strip of land which lies at the foot of Monte Barbaro and extends to lake Avernus appeared to rise and assumed the form of a rapidly increasing mountain. On the following night this pile of earth (*terrae cumulus*) began to cast forth as from a gaping mouth great volumes of fire, pumice, stones, and ashes, with a great noise, so that the surrounding country was covered up far and wide. Falconi says nothing of an elevation of the ground. The sea, he relates, retired; hot and cold springs were revealed; flames appeared on the Sudatojo (on the sea-shore), and spread towards Tripergole; there they stopped in a little valley lying behind Monte Barbaro and the hill called 'del pericolo'; through this little valley lay the way to lake Avernus; near the baths the fire attained a violence so great that in the same night the earth opened up and ejected such quantities of ash and pumice mixed with water that all the country was covered by it. Heavy black clouds and others dazzling white burst forth. The eruption continued for two days and two nights, and thus Monte Nuovo arose on the site of Tripergole. The sea covered with pumice resembled a ploughed field, and the ashes were carried as far as Calabria. On Thursday, October 3, the eruption was renewed; on the 4th it was possible to ascend the new mountain and look down into the crater, but on Sunday, October 6, many lives were

[1] INCENDIVM AD AVERNVM LACVM HORRIBILE PRIDIE CAL. OCTOB. M.D.XXXVIII. NOCTE INTEMPESTA EXORTVM.—AD PAVLVM III. PONT. Opt. Max. Hieronymi Borgii Conflagratio Averni Horrenda.—Neap. Idib. Octob. M.D.XXXVIII; also Giustiniani, pp. 233, 255.

lost in one of these rash enterprises, owing to the sudden outburst of a fresh eruption.

Mention has already been made of the fact that the sea retired two hundred feet. 'First the sea retired,' says Porzio, 'evidently owing to no other cause than this, that the vapours seeking an exit dried up the

.M.BARBARO
MISENO
C.DIBAIE
SOLFOTARA
MOTE NOVO
TERMINEDEL MARE DEPRIMA
SVDA TOIO
POTE DI CAL IGVLA
POZZVOLO
SOTTO IL MONTE NOVO STA IL CASTELLO ET ALTRI EDIFICI DI TREPERGOLE IL LAGO AVERNO STA DIETRO AL PREDETTO MONTE ET PARTE DEL MONTICELLO DEL PE RICOLO E RIMASTA SOTTO LE FALDE DEL MEDESMO

FIG. 40. *The Volcanic Eruption of Monte Nuovo and the shore abandoned by the sea*, copied from the figure in 'Dell' incendio di Pozzuolo, Marco Antonio delli Falconi all' Illustrissima Marchesa della Padula nel MDXXXVIII.'

earth, which, thus rendered thirsty as it were, sucked up the water through its fissures; and so it happened that a part of the earth which was formerly submerged by the sea became dry land, and the height of the shore was increased by ashes and other *eiectamenta*.' According to this account there was no elevation, but emergence and the accumulation of ejected

material on the newly exposed sea-floor. According to Falconi, however, the emergence occurred ten hours before the eruption; and that a very perceptible and persistent negative displacement of the strand actually occurred is shown most plainly by a rough woodcut which accompanied Falconi's account. On this (Fig. 40) will be seen below Monte Nuovo and extending towards Puzzuoli, exactly on the site of the cliff behind the Starza, the words *Termine del Mare de prima*, and a ship stranded on dry land. Only the extreme rarity of this work, which is scarcely known except in the reprint of Giustiniani in 1817, without illustrations, has caused this remarkable woodcut to fall into oblivion [1].

This disturbance of the coast-line must have made a deep impression on thoughtful minds. F. Loffredo, Marquis of Trevico, took up his residence in Puzzuoli in the winter of 1569, for the sake of his health, and devoted his enforced leisure to writing an account of the town. He describes the ruins, and mentions the ancient shore of the Starza, close to which, as he says, 'the sea still extended fifty years ago.' The Greeks, he thought, were not driven from Palaeopolis, the town which preceded Naples, by the ascent of the sea; at Baiae the sea then stood higher than at the time of the Romans, since ruins might be seen beneath the water. Further, Loffredo mentions three columns standing erect side by side behind the garden of Geronimo di Sangro, which are supposed to have belonged to the portico of the temple of Neptune, and to have fallen down from above, 'since there is no trace of an edifice worthy of them anywhere around.' Thus the temple was completely buried up in 1569, and of Cantarelle, the spring behind, Loffredo makes no mention [2].

The Cantarelle was completely choked up by the eruption of 1538. Amidst the general terror and subsequent dejection no steps were taken to protect the famous spring or to rediscover it, a fact lamented by *Capacio* in 1604. Many years later, in 1738, it was again brought to light by accident in digging a foundation deep below the ground [3].

4. *Excavation of the temple and its present state.* In 1750, when fine marble was sought for to adorn the new buildings in Caserta, it was resolved to open up the pile of débris near the three columns and to lay bare the temple. In the following account I shall trust mainly to the statements of Jorio.

[1] Giustiniani mentions a woodcut, apparently similar to that in the first edition of Porzio, which appeared without any indication of where it was printed; this I have not seen; strange to say, he does not mention the woodcut in Falconi.

[2] Le antichità di Pozzvolo et lvoghi convicini; novamente raccolte dall' Illustr. Sig. Ferrante Loffredo, March. di Treuico, &c. In Napoli, appr. Gius. Cacchij, M.D.LXX, fol. 2, a.

[3] PVTEOLANA HISTORIA a Iulio Caes. Capacio conscript. Accessit eiusd. de Balneis Libellus, Neap., 4to, MDCIIII, appendice, p. 49; N. Lanzani, Brieve dissertazione dell' acqua nuovamente rinvenuta nell' anno 1738 in Pozzuoli, dagli antichi chiamata del Cantarello, 8vo, Napoli, MDCCXL.

Near the three upright columns, and lying high above the pavement of the temple, the upper part of the shaft of a fourth column was found; but while the upright shafts are surrounded only by a band of Lithodomus borings, this fragment, with the exception of the surface resting in the débris, was perforated all over, even on the cross fractures. This piece of column, thus lying as one fragment out of many among the débris in the sea, shows that all the borings were unquestionably produced in place, and that when the sea rose to this height the temple was already deeply buried up. Further excavations revealed a great rectangular edifice 63 meters long and 56 meters broad, which turned one narrow end towards the sea, the other towards the land, and contained in the middle a semicircular cella. Before the cella stood the four great columns already mentioned. This rectangular structure, comprising many chambers, enclosed a court in the middle of which rose an independent circular building supported by columns.

Two lateral entrances were found in the eastern of the longer sides; they were blocked up with stones. The statue of Serapis had been taken from its place and set in a corner with other sculptures. In several of the chambers sculptures and fragmentary remains were found collected together, some of which it is certain did not originally belong to the temple. Two or three of these objects are evidently water-worn, and were probably brought in from an exposed position near the shore. From these facts Jorio concludes, doubtless with truth, that neither earthquake, nor fire, nor hostile invasion caused this great temple to fall into disuse, but the strict interdict pronounced against the Serapis worship by the emperor Theodosius and his successors[1]. When, therefore, in the fifth and sixth centuries, the hosts of Alaric first, then of Genseric, and finally of Totila, reached Puteoli, the temple was doubtless already deserted, but there are signs of a later attempt to adapt certain parts of it to some ritualistic purpose by the addition of walls and other structures.

The hot spring rose behind the cella, and its waters were conveyed into the interior of the temple by conduits. One of these, about one meter deep and 0·5 meter broad, led to the sea; through this the sea now enters the temple. Niccolini found beneath the first a second pavement, of great artistic merit, and a second system of conduits, which belong to an earlier structure situated at a lower level. These certainly indicate that within the Roman period a displacement of the strand-line in the positive direction may have taken place to the extent of one or two meters[2]. In opposi-

[1] Jorio, Ricerche sul tempio, &c., pp. 40, 45-48. In 1757, before the cella had been excavated, fragments of sculpture, bearing signs of having been worn by the waves, were again carried into the temple from the shore; John Nixon, An Account of the Temple of Serapis at Puzzuoli, Phil. Trans. R. S., 1757, L, part 1, p. 173.

[2] A. Niccolini, Rapporto sulle acque che invadono il pavimento dell' antico edificio

tion to Niccolini, Babbage, who in all other respects shows such deep insight, has maintained that this second pavement was only the floor of a bath; but this view is not tenable[1]. In several of the chambers dark calcareous sinter was observed in horizontal bands at different heights up to about one meter; but this sinter only shows that before the temple was submerged by the sea, cavities existed among the débris which covered it up, and in these spring or rain-water was able to accumulate. A fact of greater importance, mentioned by Jorio, is that a late Roman grave was sunk in the deposits of the cella, a proof of how quickly the ruin had proceeded.

Above the débris of the wall follows another layer of calcareous sinter, of which the lower boundary is irregular, accommodating itself to the surface of the débris, while the upper boundary is horizontal. Babbage gives about 8 feet 8 inches as the height of the latter, and adds that the sinter precisely resembles that of the *Piscina mirabilis*. This upper incrustation, visible on the shafts of the columns, was examined under the microscope by Ehrenberg, who recognized it as a fresh-water sinter[2]. At the time of its formation a pool of rain or spring-water, held up either by the débris or the wall of the great rectangle, must have stood for a considerable period. This is the last formation previous to the entrance of the sea; so far, with the exception of the deeper and older pavement, we have in my opinion obtained no chronological data, nor have we observed any indications which cannot be explained as the natural consequences of dilapidation[3].

The entrance of the sea took place gradually. The remains of the brick walls which formed the rectangle are lower towards the sea, higher towards the land; the result, as Jorio rightly observes, of the action of the waves. Sand with marine shells was now deposited, and the same bed of marine sand is found in the neighbouring gardens; towards the sea it lies at a somewhat lower level.

About this time a wall of bricks and ancient débris was constructed behind and somewhat to the side of the three upright columns and east of

detto il Tempio di Giove Serapide, letto dal Presidente della R. Accademia delle Belle Arti, 25 Nov. 1828, 4to, Napoli, 1829, 46 pp., pl.; and in the memoirs already quoted, in particular in Cisterna e antiche stufe del Tempio di Serapide, letter to L. Pasini, 4to, 1845.

[1] C. Babbage, Observations on the Temple of Serapis at Pozzuoli near Naples, with Remarks on certain Causes which may produce Geological Cycles of great extent (read March 12, 1834); Quart. Journ. Geol. Soc., 1847, III, pp. 186–217.

[2] Ehrenberg, Feststellung des Kalküberzuges am Serapis-Tempel zu Puzzuoli bei Neapel als Süsswasserkalk durch das Mikroskop; Monatsb. k. preuss. Ak. Wiss. Berlin, Sitzung vom 18. Nov. 1858, pp. 585–602. A list of marine shells is given by Philippi in Neues Jahrb. Min., 1837, V, pp. 285–292.

[3] Babbage mentions a Serpula above the lower dark sinter of one of the chambers; this only shows that one of the cavities remained for a long time unfilled. I am unable to infer from this that the sea had entered the temple before it was covered with ash.

the cella, as a defence against the sea, and doubtless to protect the spring situated behind it. This wall was built with a face sloping towards the sea; it ran across three chambers of the ancient temple, then already in ruins; its base stood 2 to 2·6 meters above the floor of the chambers[1]. This is obviously the *opus sectile* for the protection of the spring, mentioned by Petrus de Ebulo in the thirteenth century; now we perceive the appropriateness of the words: *Cum mare fremescit: locus oppugnatur ab undis.*

It was at this time that the Lithodomus made its borings. So far as the débris rose around the columns, so far were they protected from the Lithodomus and from the action of the sea generally. I visited the locality in April, 1872, and in August, 1878. On both occasions the socles of the upright columns were under water; at the second visit to the extent of 0·653 meter. If the column is examined closely the lower part of the shaft is found to be smooth and well preserved up to a height of 1·71 meters; then follows a band of sinter, here only 0·07 meter broad, evidently formed just above the ancient débris of the walls, 2·433 meters above the pavement. Up to this height the shaft retains its original diameter. Above the sinter a rough, somewhat weathered and corroded zone is seen, varying from 0·53 to 0·65 meter, and presenting towards the upper edge the chain-like borings of Vioa. Then follows, deeply corroded, and with a perceptible diminution in the diameter of the shaft, the zone of Lithodomus, the breadth of which varies roughly in inverse ratio to that of the preceding zone, from 3·02 to 2·60 meters. The upper limit of the borings was thus, in August, 1878, from 5·33 to 5·03 meters above the surface of the water in the temple, and 5·983 to 5·683 meters above the floor of the temple.

Above the borings comes a rough band of no great breadth; the upper part of the shaft has suffered a good deal from the weather, and seems never to have been under water[2].

Over the marine bed a fresh layer of débris was deposited; this doubtless was produced chiefly by the eruption of 1538; after this event more than two centuries elapsed before the excavation of the ruins. The fact that the ash rests on the marine sand proves that the positive phase was earlier than 1538.

[1] Jorio, Ricerche sul tempio, &c., p. 56.

[2] On both visits I was accompanied by younger colleagues; the measurements were made in my presence by Dr. Bittner. The shafts consist of white marble with streaks of schist; the Lithodomus may be seen following the limestone and generally avoiding the schist, while on that part of the shaft which was exposed to the air the streaks of schist are disintegrated by the atmosphere. The shafts are slightly inclined. I have not thought it necessary to lay particular emphasis on this circumstance. The floor of the temple was raised about the year 1864 by order of the sanitary authorities. I cannot assert that the water level observed by us coincided with the sea-level.

The question as to whether oscillations are still in progress is not definitely settled; the observations known to me are inadequate. Niccolini has collected a number of low-water measurements for the years 1822 to 1838, and infers from them a continuous rise of the sea; Smith thought they showed a sinking of the land; Mallet, in 1862, called attention to possible sources of error. Guiscardi asserted that a place on the bridge of Caligula where ships were formerly made fast stood on June 12, 1840, +2·037 meters, and on June 9, 1865, +2·386 meters above low water, and concludes from this that a change of level to the extent of +0·349 meter has occurred in twenty-five years [1].

5. *Divers explanations.* The first observers who, after the excavation of the temple, paid attention to the Lithodomus borings, perceived at once the difficulties presented by the problem. Most of them, residents as well as visitors, merely recorded the strange fact or expressed their conjectures with the greatest reserve. Among the foreigners who visited the ruins were Nixon in 1757, and Ferber in 1772 [2].

At first a temporary oscillation of the sea-level was thought to have occurred. Towards the close of the eighteenth century the learned *Scipio Breislak* was the leading exponent of the view that a high tide (marée), five meters high, must be supposed to have continued for several years. After the impossibility of a high tide of so great a duration had been represented to him, he abandoned this theory in the French edition of his travels in Campania, which was published by Pommereuil in 1801, confessed that no satisfactory explanation had as yet been discovered, and inclined to the view that the land itself had moved first upwards and then downwards (II, p. 12) [3].

By the side of this view another very soon arose. It was conceived that during the decay of the temple the débris had fallen in such a manner that it surrounded a basin, and indeed the rectangle of brick walls surrounding the great court would certainly tend to give this form to the accumulation. If then, owing to storms or a seismic wave, sea-water should have been driven over the ruin, a marine pond might have resulted, lying over the débris, and in this the Lithodomus might have found a home above the sea-level. This was the form of explanation given by *Pini* and by *Goethe*. *Brocchi* took a middle course, and thought that the sea had

[1] Niccolini, Gran Terma, parte geologica, p. 5 et seq.; J. Smith, On Recent Depressions in the Land, Quart. Journ. Geol. Soc., 1847, III, pp. 234–240; G. Guiscardi, Sul livello del Mare nel Golfo di Pozzuoli, Rendic. Accad. Sci. Napoli, 1865, IV, pp. 203, 204; R. Mallet, Great Neapolitan Earthquake of 1857, 8vo, London, 1862, II, p. 218.

[2] Nixon, An Account of the Temple, &c.; J. J. Ferber's Briefe aus Wälschland über natürliche Merkwürdigkeiten, &c., an Ign. Edl. v. Born, 8vo, Prag, 1773, p. 197.

[3] S. Breislak, Voyages physiques et lithologiques dans la Campanie, trad. par le Général Pommereuil, Paris, 1801, II, p. 170.

once been somewhat nearer the ruins, and the filling of the basin in the débris did the rest [1].

Later, when the elevation theory, chiefly based on the observations in Sweden, celebrated its triumph, the shafts of the columns at Puzzuoli were regarded as typical examples of the result of repeated oscillations of the land; but it is noteworthy that as late as 1829, *James D. Forbes*, after a very thorough examination of the facts, though he admitted local oscillations of the land, yet thought it possible that a general change in the level of the Mediterranean might also be in progress, and he expressly stated that this question is still in need of investigation [2].

In the account given by Forbes we perceive a tendency to regard the local movements as rapid, the general movements as slow; and about the same time *Capocci* attempted to prove that the last emergence of the land had taken place quickly, indeed during the eruption of 1538. In support of this view he referred to some of the accounts quoted here, and considered the movement to have been an elevation [3]. *Babbage*, whose careful observations have been repeatedly mentioned here, supposed that the elevations and subsidences of the ground were caused by a rise or fall of the subterranean temperature in the locality.

There was probably no one who could bring to this discussion such a thorough knowledge of the facts as *Niccolini*, whose investigations on Puzzuoli begin with the year 1808, and whose publications extend from 1828 to 1845 [4]. Niccolini always maintained that the land had remained

[1] E. Pini, Spiegazione dello strano fenomeno che presentano i vermi marini annichilati nelle colonne del tempio di Serapide in Pozzuoli, Opusc. scelti s. scienze e s. arti, 4to, Milano, XXII, 1803, pp. 94–117. Pini knew of seismic floods from the works of Krascheninikoff and Ulloa; W. von Goethe, Architectonisch-naturhistorisches Problem, 1823 (Zur Naturwissenschaft überhaupt, II, pp. 79–88). Goethe made his observations in Puzzuoli in 1787, Pini not until 1802, and did not publish until twenty years later. Von Hoff adopts the same view, Geschichte natürlicher Veränderungen, II, pp. 203–206. ‘At certain places in the province of Pasinganam, north of Arayat, salt lakes are said to occur in which, according to the statement of the priests, boring mollusca still exist, as well as in many fresh or brackish water rivers of the same province’; Semper, Die Philippinen und ihre Bewohner, 8vo, 1869, p. 100. Brocchi, Notizia di alcune osservazioni fisiche fatte nel tempio di Serapide a Pozzuoli, Bibl. Ital. Milano, XIV, 1819, pp. 193–201.

[2] D. D. Forbes, Physical Notices of the Bay of Naples: V. On the Temple of Jupiter Serapis at Puzzuoli and the phenomena it exhibits; Journ. Sci. Edinb., 1829, New Ser., I, pp. 260–286, in particular p. 283, where reference is made to the alterations in the Baltic. In favour of subsidence and subsequent elevation are: Bronn, Reisen, 1824, I, pp. 392–400; F. Hoffmann, letter in Karsten’s Archiv, 1831, III, pp. 374–383; and, in particular, C. Lyell and the repeated editions of the Principles of Geology.

[3] E. Capocci, Nuove ricerche sul noto fenomeno delle colonne perforate dalle foladi nel tempio di Serapide in Pozzuoli, 11 pp. (in the Progresso).

[4] In 1829 Niccolini published a memoir, Alcune idee sulle cause delle fasi del livello del mare, 4to, Napoli. The fundamental idea is that the sea does not gravitate towards the centre of the planet, but towards its own centre of gravity; that the latter is altered by

unmoved, and that it was the sea which had changed its level; this view he bases chiefly on the following grounds:—

(*a*) All around Italy there are visible traces of great and uniform changes of the same kind.

(*b*) Numerous thermal springs have always existed from the Roman period to the present day, and not only that of the temple of Serapis; such, among others, is the hot spring of the baths of Nero; near Gaëta a cold spring still issues from an opening of Grecian construction; any distension of the ground would have destroyed these springs.

(*c*) A number of great tunnels have also remained intact from the time of the Romans, for instance that from lake Avernus to Cumae, and the grotto of Posilippi; twice a year the setting sun sends a beam through their whole length.

(*d*) Even at the foot of Monte Nuovo the ruins of the temple of Apollo still remain standing.

(*e*) The movements are too frequent for movements of the solid land.

At the same time we must mention with admiration that Niccolini very sharply distinguished between the elevations of the mountains, distinguished by their inclined beds and the movements of the sea, which leave horizontal strand-lines; that the compensation of positive and negative movements was perfectly clear to him; and that he regarded uniform movements of an heterogeneous crust as an impossibility.

The 'metric chronological table' which Niccolini drew up for the temple of Serapis includes three phases; these are:—

1. A positive phase, from the lowest harbour works of Nisida (B. C. 200) at -6 meters, to the Lithodomus borings on the columns at $+5{\cdot}8$ meters. The maximum and termination of this phase are placed in this table between the ninth and tenth century.

2. A negative phase, said to be proved by two ecclesiastical buildings on the shore, down to about -1 meter; the latter level is given by the deeds of gift of A. D. 1503 and 1511, which cite districts regained by the sea in the neighbourhood of Puzzuoli.

3. A renewed positive phase, from a date shortly after A. D. 1511 up to the present day, and still continuing.

I will now attempt, in connexion with this table, to give the results of my own inquiry. Niccolini has misunderstood the documents of 1503 and 1511, and has underestimated the importance of the event of 1538; he

subsidences, volcanos, &c. (i. e. by tectonic processes); and that the surface of the sea must change with the displacement of the centre of gravity. As appears from a letter to Pentland, dated October 24, 1845, only a few copies of the 'Idee' were published, and the author did not return to this view. The arguments which I have cited here in favour of the stability of the continents are collected from the Descrizione de la gran Terma Puteolana, 1845.

recognized only a driving back of the sea by the accumulation of ejectamenta, as Porzio had described it, whereas a displacement of the strand actually occurred. It may also be seen, from the verses of Petrus de Ebulo and later accounts, that in the thirteenth century and at the beginning of the sixteenth the strand-line stood high. Thus we obtain the following result:—

As regards ancient times, the harbour-works of Nisida, the bridge of Caligula, the *Lex parietis faciundi*, and the double pavement in the temple of Serapis, afford evidence of positive movement only; and it is not impossible that this positive movement continued slowly through the whole period into the thirteenth, fourteenth, fifteenth, and the beginning of the sixteenth century, when the strand-line stood at +5·8 meters, the sea extended to the hot spring, and the borings in the columns of the temple of Serapis and in the piers of the bridge of Caligula were produced. Then on September 28, 1538, a sudden negative movement occurred; the Starza and the pile of débris of the temple were abandoned by the sea, and at the same time the hot spring was covered with ash. We do not know the amount of this negative movement, nor whether positive movement immediately followed; the existence of positive movement at the present day is maintained.

Hence it results also that the oscillations assumed by Niccolini cannot all be accepted as valid. *We have certain knowledge of one positive movement only, which was probably in slow progress for a number of centuries, and led to a high level which lasted from the thirteenth century to* 1538; *then a sudden negative movement during the eruption of* 1538 *or shortly before it.* Nothing else seems to me to be proved. Further, *these movements were restricted to the Phlegraean crater*, and the movements beyond Nisida which have been correlated with them are of incomparably older date.

We are dealing with a local phenomenon, in the middle of the crater, and one which presents no resemblance to those extensive oscillations of the strand-line previously discussed. The arguments advanced against the elevation theory by Niccolini, with as much penetration as boldness, can scarcely be applied to the present case.

On the other hand, the argument based by him on the uninterrupted existence of numerous hot springs from the Roman period to the present must be admitted to have great weight. It is true that the hot spring behind the cella exists to-day as it did two thousand years ago. Nevertheless it is precisely this part of the ground which in the course of this period is said first to have sunk down about 7 meters, between the time of the construction of the older pavement and the year 1538, and then in 1538 to have again risen very rapidly, indeed in a few hours, to a considerable amount, perhaps to the whole extent of 5·8 meters; and this subsidence

and elevation are supposed to have altered the structure of the ground so little that the spring is still flowing at the present day. This spring existed when the strand lay low and the Romans built the temple; it existed when the strand was high and the spring had to be protected from the waves by a wall; it was buried in ash, and in 1735 it was found again. Such persistence is hardly conceivable except in stable ground.

Thus an examination of the facts confronts us with a singular problem, for on the one side we see the locally restricted nature of the changes near Puzzuoli, on the other the constancy of the springs and many other conditions in the solid land make it difficult to believe that the land actually slowly subsided, then suddenly rose again, and is perhaps now once more sinking.

On December 8, 1861, an eruption of Vesuvius took place, which was instructive in many respects. We extract the following from Palmieri's account[1]:—

As early as December 5, violent vertical oscillations were recorded by the magnetic variation apparatus of Lamont in the Observatory; the oscillations increased, the earth trembled, and on December 8, at three o'clock in the afternoon, a great fissure opened on the south-west side of the mountain towards Torre del Greco at a height of 290 meters. Augitic lava poured forth. Towards eleven o'clock in the evening the activity diminished; on the morning of December 9 there was a temporary increase, and the principal crater of Vesuvius began to eject bombs and scoriae. The fissures were prolonged through Torre del Greco to the sea; in some localities their sides were widely displaced with regard to each other; they traversed the lava of 1794, and many houses collapsed. On the 10th there was an extraordinary increase in the outflow of the public springs of Torre del Greco. The carbonic acid poured out of the ground with such violence as to raise the heavy slabs with which the streets are paved. The waters of a little spring on the seashore increased in volume; in the sea itself a long zone of violent commotion was observed. This, as it appeared later, was caused by escaping carburetted hydrogen. On the shore below Torre del Greco it was now observed that *the sea-level stood* 1·12 *meters lower than a line of seaweed and shells which marked the former strand-line.* Palmieri thinks that this shows the ground had been raised. This elevation appears to have been the chief cause of the widening of the fissures in Torre del Greco; and for this reason that part of the town built on the ancient lava had suffered most, since the lava was broken up by the swelling of the ground.

[1] L. Palmieri, Cronaca del Vesuvio, Ann. R. Osservator. met. Vesuviano, Napoli, 1862, III, p. 1 et seq., and Compt. Rend., Paris, 1861, LIII, p. 1232; Guiscardi, tom. cit., p. 1235; Tchihatchef, Verh. k. k. geol. Reichs. Wien, 1862, p. 182; Perrey, Note sur les tremblements de terre de 1861, p. 104 et seq.

The eruption from the principal crater continued, while the vents situated on the upper part of the new fissure were emptied to an extraordinary depth, notwithstanding the brief duration of the outflow.

Accounts exist which might lead us to suppose that during some of the earlier eruptions, especially that of the year 1631, *an elevation of the land had also occurred, followed by a subsidence.* In 1861 the negative movement did not extend as far as Granatello, 4 kilometers to the north-west; and in Torre Bassano, 2·25 kilometers to the south-east, it only amounted to 0·3 meter. A fixed point was therefore chosen at Granatello, and on December 31 a line of sight was established upon an islet between this point and a reference mark on the raised shore near Torre del Greco. On January 21 the reference mark was already found to be 0·64 meter lower, on February 12 it was 0·136 meter lower still, but on March 8 the reading had not changed; by March 31 it had sunk 0·041 meter further, making altogether 0·241 meter since December 31. At the same time the shore began to show signs of great heat; some springs on the beach reached a temperature of 47° by the end of January. The vents which had opened on December 8 had already long been closed, but the temperature at Torre del Greco and on the shore continually increased, until finally, on March 2, a long stretch of ground had reached 30°, and began to give off steam. Palmieri was of opinion that the liquid lava could not be more than 500 meters below the town of Torre del Greco, and it was expected that a new eruptive centre would open at the surface. At the same time the levelling apparatus indicated a continuous positive movement—interrupted, it is true, at the very beginning of March—which in this case corresponded with a subsidence of the ground.

The volcanic eruption on *Tanna,* the most southerly of the New Hebrides, on January 10, 1878, was accompanied by a negative displacement, the exact extent of which, probably about 3 meters, cannot be discovered from the accounts; nor do I know whether it was followed by a positive recurrence[1].

These cases, particularly that of Monte Nuovo in 1538 and Vesuvius in 1861, show a slow positive and a rapid negative movement. All the facts might be most readily explained by a decrease of gravitational attraction consequent on the eruption, but calculations lend no support to this suggestion.

In 1845 Bruchhausen published a treatise, in which he attributed the rise of the sea during glacial periods to the attraction of the accumulated masses of ice; and Penck remarks that in 1846 the same author presented Humboldt with a manuscript as a supplement to this treatise, in which

[1] Annalen der Hydrographie, Berlin, VI, 1878, p. 371. Captain Kilgour says that a rock in front of the harbour appeared to have risen three meters, and coral reefs were raised out of the sea. Here also a seismic flood occurred.

he maintained that in consequence of volcanic activity a change may take place in the local value of gravity, and therefore in the sea-level also[1]. Verbeek estimated the mass of material ejected by Krakatoa in August, 1883, at 18 cubic kilometers, with a weight of 36×1012 kilogrammes. Still higher estimates were given by Junghuhn in the case of the eruption of Tambora in 1815[2]. After the eruption of Monte Nuovo, Francesco del Nero wrote: 'What I cannot make out is the great quantity of material which has issued from this vent . . . and God forbid that the cavity should extend beneath Naples[3].' None of these masses, however, are sufficient, according to the calculations of our physicists, to account for the negative movements recorded.

Thomson and Tait calculate that we should have to assume a subterranean spherical cavity of 3,000 to 4,000 meters in diameter to account for a fall of one meter in the sea-level. Drygalski has calculated the cavity for the temple of Serapis, but with the centre below Vesuvius[4]. Dr. Margules has had the kindness to undertake at my request a number of these laborious calculations, and has arrived at results identical with those of his predecessors. Thus according to him, we find first, in agreement with Thomson and Tait, that a spherical cavity beneath the surface of 190 cubic kilometers would be required for a subsidence of the sea-level to the extent of one meter. If we assume a hemispherical cavity, its volume would amount to 147 cubic kilometers; and by assuming the most favourable conditions this would be reduced to 104 cubic kilometers. These figures are all disproportionately greater than the highest estimate of the most voluminous discharges, and in the case of Monte Nuovo we have a negative movement not of one, but of five or six meters.

The question, then, arises whether we must not return to the old theory of Babbage, which attributes the swelling up to increase of temperature. Palmieri appears to think that this cause has been supplemented by the action of high-pressure vapours.

Whatever may be the true explanation, these movements which have left their traces on the columns of the temple of Serapis are completely different from those of the Baltic sea, although they find a place beside

[1] W. von Bruchhausen, Die periodisch wiederkehrenden Eiszeiten und Sindfluthen, 8vo, Trier, 1846; A. Penck, Schwankungen des Meeresspiegels, 8vo, München, 1882, pp. 7 and 19 (printed from the Jahresber. geogr. Ges. München, VII). The fact of the constant elevation has not been established. Prof. Penck has been kind enough to send me a copy of this MS.

[2] R. D. M. Verbeek, Rapport sommaire sur l'éruption de Krakatau, les 26, 27 et 28 août 1883; Arch. néerland. sci. Harlem, 1884, XIX, p. 166.

[3] M. Neumayr, Der Bericht des Francesco del Nero über die Bildung des Monte Nuovo bei Neapel; Neues Jahrb. Min., 1883, II, p. 49.

[4] Thomson and Tait, Handbuch der theoretischen Physik, I, 2, 8vo, Braunschweig, 1874, § 787, p. 342; E. von Drygalski, Die Geoid-deformationen der Eiszeit, Zeitschr. Ges. Erdkunde, Berlin, 1887, XXII, p. 28.

one another in our textbooks as proofs of the theory of elevation; in the first place they are distinguished by their strict local limitation, and in the second by the sudden spasmodic character of the negative phase. They have as little in common with the alleged universal and secular oscillations of the continent as the oscillations of an inland sea with those of the Ocean. They are changes above the surface of a scoria-covered focus, and neither the fresh verdure of the hills and meadows, nor the noisy traffic of the light-hearted inhabitants, nor historical recollections, permit us to forget that Horace's 'little corner of the smiling earth,' the promontory of Misena, looks down into the depths of an expiring volcano, not yet absolutely extinct. An explanation of these phenomena must be sought in active volcanos, on the slopes of Vesuvius, or still better, on the 'pahoëhoë' of Kilauea, the lava field in the interior of the great crater of Hawaii.

CHAPTER X

THE BALTIC AND THE NORTH SEA DURING THE HISTORIC PERIOD

Salinity within the Skager Rack. Mean level of the Baltic on the German coast. Oscillations on the coasts of Sweden and Finland. General survey of the negative displacement. Submerged forests and peat bogs of the North sea. The haffs and peat bogs of the Baltic coasts.

1. *Salinity within the Skager Rack.* When, in 1807, Leopold von Buch perceived the signs of a retreating strand in the gulf of Bothnia, he was dominated by the belief that the whole surface of the ocean stands at the same level, and that a local deviation from uniformity is a 'matter of impossibility.' Out of this conception arose the theory of continental oscillations, with all its consequences, which has so profoundly influenced the development of our science. Yet this notion of a uniform level cannot be maintained; apart from the very important disturbances, still insufficiently studied, which are due to the attraction of the continents, it certainly cannot be applied to interior seas more or less separated from the Ocean.

If we assume a complete equalization of level in the most distant arms of the sea, we might with the same right imagine a similar equalization in the salinity and density; which, nevertheless, does not occur. We must, on the contrary, admit that the water *in those bays or incompletely closed arms of the sea, where the density is less than that of the Ocean, stands at a higher level, and in those where it is greater at a lower level than the Ocean.*

Salinity is the most important element in determining the density of the water. Temperature, except as a factor in evaporation, has less influence, and its effect is less strictly localized than the differences in salinity. When the estuary of a river is filled with fresh or brackish water, then a higher column of the less heavy water in the estuary is required to balance a column of the heavier water in the open sea. For this reason alone the shore-line must be higher within the estuary than outside it. The salinity and the level of the water in the estuary are dependent on the quantity of fresh water brought down from the land, and this varies with the seasons, so that we should expect to find the greatest variations both in level and salinity in proximity to the mouths of rivers.

According to the data of the *Deutsche Seewarte* the North Atlantic Ocean attains its maximum density in lat. 30° to 35° S., with a specific

gravity of 1·02768, and 3·63 per cent. of salts in solution; both salinity and density decrease to the north and south. In lat. 50° to 55° N. the specific gravity is 1·02665, the salts in solution amount to 3·48 per cent.[1] We must refer to these values as a standard in discussing the partially closed arms of the sea.

In Europe there are two chains of seas in somewhat restricted communication with the Ocean. The first of these comprises the gulf of Bothnia, the gulf of Finland, the Baltic, Cattegat, and Skager Rack; the second includes the sea of Azov, the Black sea, the Bosphorus, the Aegean, and the Mediterranean. In those most remote from the Ocean, that is the 'wiek' or northern half of the gulf of Bothnia, the gulf of Finland, and the sea of Azov, the same conditions prevail as in a great estuary; the salinity is at a minimum; they should consequently present the highest level above the Ocean.

In the northern chain the following members may be distinguished:—

I. *The northern half of the gulf of Bothnia, or the wiek of Bothnia*, bounded on the south by the Quarken. It forms a shallow basin, which sinks, it is true, to below 100 meters on the west side, between lat. 64° and 65° N., and in one place even to 129 meters; but on the whole the depth is inconsiderable. Towards the north-east there is less than 20 meters of water over wide areas, and the transverse ridge of the Quarken nowhere appears to sink below 20 meters[2].

The quantity of water which enters the basin bounded by this ridge is always very great, but varies with the seasons to an extraordinary extent. The watershed on the west of the basin is situated far away towards the Atlantic; on the north it is almost equally remote, and only on the north-east and east does it gradually approach the Quarken. The vast volume of snow water set free by the sun during the long summer days, which are scarcely interrupted even by twilight, flows into the wiek of Bothnia. The greater quantity comes from the west. The whole of this influx must pass out over the ridge of the Quarken, and chiefly over that part of it which lies between Holmö and the coast of Sweden, an interval only 16 kilometers in breadth. The result is an extremely low degree of salinity. At Nieder-Kalix, near the northern end of the gulf, Edlund found only 0·26 per cent. of saline constituents, at Skellefteå 0·35, and at Umeå, in the waist of the Quarken, 0·39. Off the northern part of the Finnish coast Struve found at Uleåborg and at Brahestad 0·34 per cent.[3]

[1] G. von Boguslawski, Handbuch der Oceanographie, 8vo, Stuttgart, 1884, I, p. 149.

[2] This may be very clearly followed on the bathometrical chart of the Baltic by E. Ackermann and E. H. Wichmann in Ackermann, Beiträge zur physischen Geographie der Ostsee, 8vo, Hamburg, 1883.

[3] These are the figures reduced by Ekman to a common denominator; Ekman, Om Hafsvattnet utmed Bohuslänska Kusten, K. svenska Vet. Akad. Handl., 1870, 2. ser., IX, 1. part, No. 4, p. 30.

II. *The southern half of the gulf of Bothnia.* This extends from the Quarken to the Åland islands. The islands are the summits of a broad rocky ridge which extends from Åbo towards the west, but terminates before reaching the Swedish coast in an abrupt descent to an unexpected depth. A narrowly confined trough is thus formed, with a bottom below 200 meters, and towards the south-east even below 300 meters; it is situated at the junction of the gulf of Bothnia with the northern Baltic, and is known as the *sea of Åland.*

Between the Åland islands and the Quarken the sea sinks in yet one other place to a great depth; this is also on the west coast, in lat. 62° 53′ N.; soundings show −271 meters. From this spot the depth rapidly diminishes to the north, east, and south, so that the mean depth of even this basin is by no means great.

The drainage basin which supplies this sheet of water is quite as broad on the western side as that of the northern moiety of the gulf of Bothnia, but on the east it is more restricted, and the influx of fresh water is far less. Thus it happens that the salinity shows a general increase towards the south, but on the coast of Finland the increase is already felt more to the north; thus, south of Wasa, lat. 63° N., Struve found 0·51 per cent., and at Kristinestad, lat. 62° 15′ N., 0·54 per cent.; while on the Swedish coast, at Hernösand, lat. 62° 30′ N., Edlund found only 0·42, at Söderham, lat. 61° 11′ N., only 0·46, and north-east of Gefle, lat. 60° 51′ N., only 0·48 per cent.

III. *The gulf of Finland.* This contributes a considerable quantity of fresh water, which it receives from the east. The depth of the gulf increases in a gradual and regular manner from the Neva to the Baltic, and subterranean ridges, such as those of the Quarken and the Åland islands, are absent. For the question now before us a closer description of this gulf is not necessary.

IV. *The gulf of Riga,* situated on the inner side of the islands of Dagö and Oesel, receives the drainage of the basin of the Düna, and contributes a certain quantity of fresh water.

V. *The Baltic.* This sea is divided longitudinally down the middle by a ridge, which runs, with only a trifling interruption, from the Kopparsten-örne and the island of Gotska Sandö, across Gothland and the Hoborg bank to the Mittelbank; that is, from about lat. 58° 30′ to 55° 30′ N. Bornholm and the Rönne bank may also be considered, so far as the movement of the water is concerned, as its continuation. Thus there arises a German moiety of the Baltic, that is, the east, south-east, and south part, and a Swedish moiety, that is, the west and south-west part. The greatest depths in the German moiety occur east of Gothland, where the sea sinks over a wide area to below 200 meters, and attains a maximum of −249 meters; in the Swedish moiety they are found north-west of

Gotska Sandö, where the deep region is less extensive, but deeper; a sounding gives −323 meters, the greatest depth found anywhere in the Baltic. It is very remarkable that throughout the whole distance from the latitude of Gothland to the Skager Rack such depths as these are never again encountered.

The three passages by which the Baltic communicates with the Skager Rack differ in character. A depression, reaching a depth of more than −20 meters and continued into the bay of Lübeck, finds its prolongation to the north-west in a channel which subdivides into the two Belts, the Little Belt on the one hand, and on the other the Great Belt, the latter proceeding to the still deeper waters lying north-west of Zealand. The Sound presents towards the Baltic a broad funnel-shaped entrance, but its depth between Copenhagen and Malmö is trifling, and only in the narrowest part does it sink below −20 meters; the deeper channel in this place grows broader beyond Helsingborg and enters the Cattegat.

The Baltic receives a number of German rivers from the south. To this supply we must add the contributions from the gulfs of Riga, Finland, and Bothnia. From the northern part of the Swedish coast, also, considerable quantities of fresh water reach its basin; but, owing to the distribution of the watershed, the southernmost part of Sweden does not receive the drainage of the higher mountains, the rivers diverging to the south-east and south-west. Thus the southern end of the Scandinavian peninsula forms to a certain extent an independent hydrographic region, and its contribution to the fresh water of the Baltic is comparatively trifling.

We possess a large number of exact observations on the currents and salinity of the Baltic, the result of the combined efforts of Swedish, Danish, and Russian investigators, and as well of the invaluable work of the German ship *Pommerania* and the Commission for the scientific investigation of the German seas; we can only quote a few examples[1].

Let us first return to the trough in the sea of Åland. Here, Forchhammer found a salinity of 0·592 per cent. at the surface, 0·725 per cent. at a depth of 50 fathoms, 0·747 per cent. at a depth of 100 fathoms, and 0·750 per cent. at a depth of 158 fathoms[2]. Thus in this isolated trough heavy water lies at the bottom, and the lighter water streams away above. Since the salinity increases on the whole towards the south, we encounter in this direction surface densities which make a continually nearer approach to the densities of the deep water further to the north in the sea of Åland.

[1] Many of these have been collected by J. Roth, Allgemeine und chemische Geologie, I, Berlin, 1879, pp. 555 et seq. Of the older works I will only mention Baron A. F. Sass, Resultate aus meinen Untersuchungen über die Variationen im Salzgehalte des Ostseewassers; Zeitschr. ges. Erdkunde, Berlin, 1867, II, pp. 481–498.

[2] G. Forchhammer, On the Composition of Sea-water in different parts of the Ocean, Phil. Trans., 1865, CLV, pp. 203–262; Ekman, tom. cit.

At the same time, there is a good deal of variation according to the season, the direction of the wind, and other circumstances. At the mouth of the gulf of Finland (Forchhammer), and between Dagö and Oesel (Göbel), the salinity is 0·69 per cent.; thence to beyond Bornholm the salinity of the surface water varies from 0·71 to 0·75, or sometimes even to 0·78. In the deeper water, however, the salinity is greater, and in the sea between Jershöft and Bornholm, at −85 to −90 meters, a percentage of 1·633 was observed. From the neighbourhood of Warnemünde onwards the salinity at the surface has already risen to over 1·0 per cent.

We now approach the entrances of the Baltic. The heavy water of the North sea finds its way in through the deep channels of the Belts, while the light water of the Baltic flows out over it; but during calm weather comparatively little water passes from the North sea through the Sound, which is crossed by the shallows of Drogden, and turns its funnel-shaped mouth towards the Baltic. An interchange takes place under special conditions, which we must examine now more closely in the light of the detailed and invaluable descriptions of Meyer and Karsten [1].

The mean salinity at the surface in the regions east of Arcona, in the island of Rügen, and of Ystad in Scania, may be taken as 0·75 per cent., off the coast between Rügen and Fehmarn at 1·0 per cent., in the Sound at 1·25, off the coast of Schleswig-Holstein at 1·75, off the Danish coast of the Cattegat at 2·33, at Skagens Rev in the Skager Rack at nearly 3·0, and in the adjacent parts of the North sea at 3·25 per cent. When high winds blow steadily from the Cattegat for any length of time the undercurrent in the Belts grows stronger, and the heavy water in the Sound passes over the shallows of Drogden. A great quantity of salt water then accumulates in the south-western part of the Baltic, and an increased salinity is perceptible as far as Rügen, and even beyond. The subsequent fate of the heavy water thus introduced is not known; it probably descends into the depths situated east and west of Gothland. Some years may then elapse, the salt in the heavy water continually diffuses into the lighter, and this process of extraction continues, till a fresh irruption of sea-water occurs again.

In 1869, and again during the storms of October 31 to November 1, and November 7 to 11, 1872, large quantities of salt water were thus driven into the Baltic, and could be traced to the east of Rügen. Then, on November 13, there came out of the east and north-east the great cyclone, of which we shall speak later, and drove the water in the opposite direction

[1] H. A. Meyer, Periodische Schwankungen des Salzgehaltes im Oberflächenwasser in der Ostsee und Nordsee, IV. Bericht der Commission zur wissenschaftlichen Untersuchung der deutschen Meere, VII.–XI. Jahrg., 3. Abth., fol., Berlin, 1884, pp. 1–10; and G. Karsten, Die Beobachtungen an den Küstenstationen und Schiffsbeobachtungen, tom. cit., pp. 11–60.

into the North sea. In the winter of 1873–4 heavy water was again introduced. Lohme in Rügen and all the stations to the west showed an unusually high salinity. This decreased up to the year 1875; and from that time onwards the salinity in the whole of this part of the sea experienced a much slower but continuous decrease, which lasted for seven years. In the spring of 1882 heavy water again entered, but without quite restoring the salinity of previous years.

The salinity of the Baltic, as Karsten observes, is thus at present dependent on the periodic irruption of water from the North sea; and east of a line drawn from Rügen to Ystad, the Baltic presents the character of a great brackish-water lake. Since its earlier communication with the sea, a continual freshening of its waters must have taken place, and the question arises whether this is still in progress, or whether a state of stability has been reached. The gradual decrease in salinity during a series of years, and the variations which regularly follow the seasons, show the great influence of the rainfall [1].

Karsten estimates the whole volume of the water in the Baltic at 75 cubic miles, and the annual contribution of fresh water at 1·5 cubic miles; so that if the form of the basin were simple, and if its contents could be completely displaced across the entire transverse section, fifty years would suffice to fill the Baltic with fresh water. But, as it is, the freshly introduced heavy water sinks to the bottom, and in isolated places of small extent, as, for example, in Wittlings Kuhle in Kiel harbour, preserves a high salinity for a long period. At the same time, a continuous influx of water from the North sea, not sufficient, however, to render the salinity uniform, enters through the deep channels of the Belts.

Under these circumstances a peculiar movement of the waters takes place outside the entrances, in the Cattegat and Skager Rack. Three currents exist. The first is the great oceanic stream, which washes the west coast of Jutland, enters the Skager Rack, and may even be observed on the Swedish coast opposite Skagen; it then turns outwards and follows the west coast of Norway. As far as this current extends the ebb and flow of the tides are clearly marked, but further towards the Baltic they become increasingly obscure. The second current branches off from the first, and enters the Baltic as salt water in the way we have just described. The third is the less saline outwards-flowing current of the Baltic, which follows the Scandinavian coast to beyond cape Lindesnäs. The numerous rivers of the southern part of the peninsula open on this part of the coast and assist in lowering the salinity.

The investigations of Ekman off the coasts of Bohuslän give a clear idea of the existing conditions. Sometimes three layers of water may be distinguished on these coasts: an upper layer derived from the rivers, which

[1] Karsten, mem. cit., p. 40.

probably never extends deeper than 2 fathoms, beneath this the Baltic current, and beneath this again the saline water. In the parts of Bohuslän next the Cattegat we find at the surface of the Baltic current about 2 per cent. of salt, at a depth of 10 fathoms 2·5 per cent., and at about 15 fathoms 3 per cent.; but further north on the coast bordering the Skager Rack 2·5 per cent. is found at the surface. Where the Götha-elv enters the sea we first meet with 2·5 per cent. at a depth of 2 fathoms. The water of the North sea may be recognized by its blue colour, and sometimes the dividing line is so sharp that at some miles from the coast water of a different salinity may be found on opposite sides of a boat. This affords the only explanation of the fact that on the Fjällbacka-Skärgard in the Wäder islands, which proceed from north Bohuslän into the Cattegat, Ekman observed a change of salinity during the night to the extent of 0·23 per cent.

As regards the Skager Rack, we may introduce here a transverse section taken by the German ship *Pommerania*. In the harbour of Arendal a salinity of 1·083 per cent. was observed; in the Skären of the Arendalfjord, 1·572; 12 miles north-west of Skagen, 2·83; 10½ miles north-west of Skagen, 2·95; 3 miles north of Hirshals in Jutland, 3·28 per cent.

2. *Mean level on the German coast.* The water of the Baltic is influenced, as we have seen, by so many different circumstances that a long series of observations and a careful examination of the data are necessary before we can arrive at a determination of the mean level at any locality, or form an opinion as to whether a positive or negative displacement of the level is now taking place at any given point or not. From an examination of a great number of observations, made at many places on the German coast in the eighteenth century and up to the year 1875, Hagen arrived at the conclusion in 1877 that no elevation or subsidence whatever was taking place on this coast, but that the water sometimes maintains a higher level than the normal for as much as a whole year, and that consequently the Baltic has not always the same height[1]. Additional information of

[1] The difficulties attending investigations of this kind may be seen from the variety of results obtained in the course of years by so exact an observer as Hagen. A first comparison of the heights recorded by the tide-gauges on the German coast in 1810–1844 showed for Colbergermünde a trifling elevation of the sea-level; for the neighbouring town of Swinemünde and all the harbours of the provinces of Prussia, on the other hand, a subsidence of the level, increasing towards the east with a certain regularity. Doubt, however, was felt as to the constancy of certain gauges; in 1845 control levellings were made, and in 1846–1864 these showed an actual oscillation of the sea-level at certain places, but this was ascribed to the wind. At the same time the influence of the seasons on the sea-level became apparent. With the further continuation of the observations to 1875, Hagen maintained that lasting elevation or subsidence did not occur; that the trifling deviations could be explained by alterations in the course of neighbouring currents; that in some years a higher level may be maintained (e. g. in 1874, 4–8 inches) without being caused by the wind. We must, therefore, infer *that the Baltic has not*

a very trustworthy nature is to be found in the two monographs by Wilhelm Seibt on the mean level at Swinemünde and Travemünde. It appears from the observations at Swinemünde during the years 1826 to 1879 that the mean error of the probable change in the relative level is greater than the observed change itself, and therefore that the constancy of the level of the Baltic for this purpose must be regarded as proved. At Travemünde the mean error deduced from the series of observations made in the years 1855 to 1884 approaches so closely to the change observed that here also constancy may be inferred.

Further, the important fact has been observed that, in spite of the lower salinity of this part of the Baltic, its mean level stands at the same height as that of the North sea at Cuxhaven, or rather that the differences observed are less than the mean error. As bearing on some remarks to follow, it is important to note that this close agreement has been obtained by leaving the station of Memel out of account. For while Pillau, as compared with Cuxhaven, gave a height of + 75·9 mm. with a mean error of ±79·6 mm., from which identity of level may be inferred, Memel, on the other hand, gave +221·1 mm. ± 98·0. Thus Memel, which of all the German stations advances furthest into the Baltic, certainly affords evidence of a considerable positive displacement[1].

We may conclude from these observations that the Baltic, all along the German coast as far as Pillau, is able to maintain itself in equilibrium with the Ocean through the Belts, though the water may sometimes stand at an exceptionally high level for several years; but beyond Pillau we have no proof that this is the case, and the mean level at Memel stands at a greater height. Persistent displacement of the mean level, either upwards or downwards, cannot be shown to occur in this part of the coast.

3. *Oscillations on the Swedish and Finnish coast.* The opinion expressed by Nordenanker in 1792, that the Baltic is an inland sea with an incompletely open outlet, and that the oscillations of the strand-line are merely the result of irregularities either in the supply or discharge (II, p. 10), has been adopted by many subsequent observers. In 1823 Nilsson expressed himself in its favour. *Robert Chambers* supported it in a paper which he

always the same height; G. Hagen, Die preussische Ostseeküste in Betreff der Frage, ob dieselbe eine Hebung oder Senkung erkennen lässt, Abh. k. Akad. Wiss. Berlin, 1865, math. Abth., pp. 21–41; by the same, Vergleichung des Wasserstandes der Ostsee an der preussischen Küste, op. cit., 1877, pp. 1–17, and Vergleichung der von 1846 bis 1875 an der Ostsee beobachteten Wasserstände, Monatsber. k. Ak. Wiss. Berlin, 1877, pp. 559 to 561. Baron Sass arrived at the same results; Untersuchungen über die Niveau-Verschiedenheit des Wasserspiegels der Ostsee, Erman's Archiv, 1867, XXV, pp. 320–348.

[1] W. Seibt, Das Mittelwasser der Ostsee bei Swinemünde, Publicat. des k. preuss. geodät. Institutes, 4to, Berlin, 1881; and by the same, Das Mittelwasser der Ostsee bei Travemünde, op. cit., 1885.

communicated to the Swedish Academy. On November 14, 1849, he maintained that the supposed constancy of level in the Baltic rested on no sufficient proof; on the contrary, by reason of its numerous affluents, this sea must be regarded as a great estuary, its affluents may diminish in volume and its channels of egress become enlarged; a determination of level was consequently indispensable. Two distinguished investigators, *A. Erdmann* and *Lovén*, were prompted by this memoir to institute a fresh series of connected observations. It seemed to them probable that the interior waters stand at a higher level than the open sea, and that the wiek, the gulf of Bothnia, and the Baltic form three basins rising out of the sea in successive steps. Swedenborg, as early as 1719, had maintained that these inland waters stand at a comparatively high level. Woldstedt, when engaged on the triangulation of Finland, found that the sea-level at Uleåbord stood 16 feet higher than in the gulf of Finland, and though this value may perhaps err in excess, it nevertheless deserves attention [1].

While the importance of fresh observations was thus becoming recognized in Sweden, the subject received renewed attention in Finland. *Albin Stjerncreutz*, an experienced mariner, who as director of the pilotage of Finland was peculiarly well qualified to form an opinion, declared himself strongly in favour of Nordenanker's view. He at the same time gave a description of the various currents of the interior parts of the sea; variable currents dependent on the wind occur at the surface, and below these the great normal currents, which all tend towards the several exits of the Baltic and depend for their sole motive force on a head of water driving them into the Ocean [2].

In the year 1850 systematic observations were commenced under the direction of A. Erdmann, and regular daily measurements of level were made at a number of lighthouses around the whole of the Swedish coast. As early as 1855 a preliminary summary of the results was published, but this revealed numerous sources of error [3]. *L. Holmström* was then deputed to visit all the stations of observation and to scrutinize the method employed at each place. Next *Forssman*, making use of the series of observations recorded from 1852 to 1875, attempted a fresh co-ordination

[1] Nilsson, Utkast till en geologiske Beskrifning öfver Skåne, Physiogr. Sällsk. Årsberätt. Lund, 1823, in particular p. 5; Erdmann och Lovén, Östersjöns medelniveau, Öfvers. K. Vet. Akad. Förh. Stockholm, 1850, VII, pp. 36–49.

[2] Albin Stjerncreutz, Anmärkningar rörande strömmarne i Östersjön; Act. Soc. Sci. Fennicae, Helsingfors, 1861, VI, pp. 369–393, Föredrag, 1859.

[3] A. Erdmann, Om de Iagttagelser öfver Vattenhöjdens och Vindarnes Förändringar; Öfvers. K. Vet. Akad. Förh. Stockholm, 1855, ny följd, I, a, pp. 247–303, map. The position and other details relating to many of the points mentioned here have been given by J. A. Fagerholm, Nivelliringar och undersökningar af Vattenhöjdstationerna vid en del af Sveriges fyrar, utfor i sommaren 1878, Öfvers. K. Vet. Akad. Förh., 1879, XXXVI, pp. 21–37, maps.

of the facts, and obtained important results[1]. The work of Dr. Holmström, extending over many years, has not yet been published, but, with a rare disinterestedness, he has had the kindness to furnish me with some of his most important data; in particular, the readings taken from thirty-three gauges or marked rocks distributed round the Swedish coast; he has also provided me with a critical discussion of the relative importance and value of the ancient marks of reference. I have also received much valuable assistance towards the study of this phenomenon in Sweden from my esteemed friend, Professor Nathorst of Stockholm.

Side by side with the work of Swedish investigators must be mentioned the monthly mean levels recorded at eight stations on the coast of Finland, some of which date from 1858. They have been published without interruption by *Moberg*, and are of great importance in relation to this question[2].

As an essential preliminary, we must begin by distinguishing between continuous series of measurements and occasional readings taken from marks cut in the rocks.

Forssman gives tables of monthly means from 1852 to 1875 for thirteen stations; but five of these, it must be observed, are situated north of the Åland islands, where, owing to the rigorous winter, no observations are made during four to six months of the year. On the other hand, the records kept in Finland, as far up as Rönnskär, lat. 63° N., are complete for each month.

As regards the occasional readings, a difficulty arises from the fact that we have no knowledge of the mean level at the time they were taken, and that the height of the water is affected by a number of local and temporary circumstances. In Finland, transitory oscillations may occur amounting to more than six feet in the course of a single year, that is, to as much as the alleged negative displacement during a century and a half. In connexion with this, Dr. Holmström writes, 'In the Cattegat the so-called *Tangrand* occurs, that is, the highest continuous line on vertical cliffs up to which *Fucus vesiculosus* grows. The tang-line coincides very closely with the level of mean tide, or that level which the people on the coast call "lagligt vatten." It appears never to lie more than from 9 to 10 centimeters below the mean tide level, as directly observed at the light-houses. In the Baltic, however, there is no tang-line, or at least it is not well defined; but on the other hand another line, the so-called *Algrand*, is found there: this is the highest limit to which certain species of delicate algae grow. In what relation this line stands to the mean tide level,

[1] L. A. Forssman, Observationer öfver Vattenhöjden vid Sveriges Kuster; Öfvers. K. Vet. Akad. Förh., 1874, ny följd, XIII, ii, 23 pp.

[2] A. Moberg, Om Finska Kustens höjning under åren 1858–1872; Öfvers. Finska Vet. Soc. Förh., XV, 1872–1873, pp. 118–128, and the tables in the following years.

or even whether it remains at the same height for several years, as the tang-line certainly does, has not yet been determined.' Thus, not only scientific observations, but the statements of the inhabitants on the shore are of more value in the Cattegat than in the wiek of Bothnia.

We now pass to the series of continuous observations. From these Forssman has already obtained two very important results, which find confirmation in observations made elsewhere.

The first is derived from the *monthly means*. Every year the mean level of the sea fluctuates with the seasons; it does so from the islands of Åland to the coasts of the Skager Rack, or indeed as far as the Swedish coast extends. The curves are uniform, and the incomplete curves obtained from the region north of the Åland islands, where winter observations are wanting, adapt themselves to the others. Towards the Cattegat, however, the maximum is felt later than elsewhere. In the Baltic low water occurs in April and May; then the level rises along the whole east coast of Sweden, attains a considerable height in July and August, and remains high until November or December, when it begins to fall once more. In the Cattegat the maximum is reached somewhat later—towards the end of September or the beginning of October, and is more quickly over. The curves of changing level on the east coast correspond, however, to the annual variations in the rainfall, as determined by Rubenson [1].

In connexion with this question it may not be without interest to observe that lake Ladoga, as shown by Woeikof's tables, is as equally subject to seasonal oscillations as the Baltic [2]. But even outside the Baltic the influence of the seasons on the level of the water still makes itself felt on the less saline stream of the Baltic water which flows along the west coast of Sweden.

The monthly means show that as regards the seasonal oscillations the Baltic stands as a middle term between the Russian lakes and the Skager Rack.

The second result obtained by Forssman is derived from the *yearly means*. So far as yearly means have been determined, that is from the lock of Stockholm to the station of Nord Koster in the north of the Cattegat, the yearly oscillations present a remarkable uniformity. In 1853 the level was everywhere low, in 1854 everywhere high; then it sank; in 1857 there was a low level from Stockholm to Ystad, but, as an exception, this did not extend into the Cattegat; the succeeding depression of 1860, however, was felt on both coasts, and equally so the well-marked

[1] R. Rubenson, Nederbördsmängden i Sverige, tom. cit., No. 10; cf. in particular pl. i, fig. 1, in Rubenson with fig. 1 in Forssman.

[2] A. Woeikof, Schwankungen des Wasserspiegels der grossen amerikanischen Seen und des Ladoga-Sees; Zeitschr. österr. Ges. Meteor. Wien, 1881, XVI, pp. 287–290.

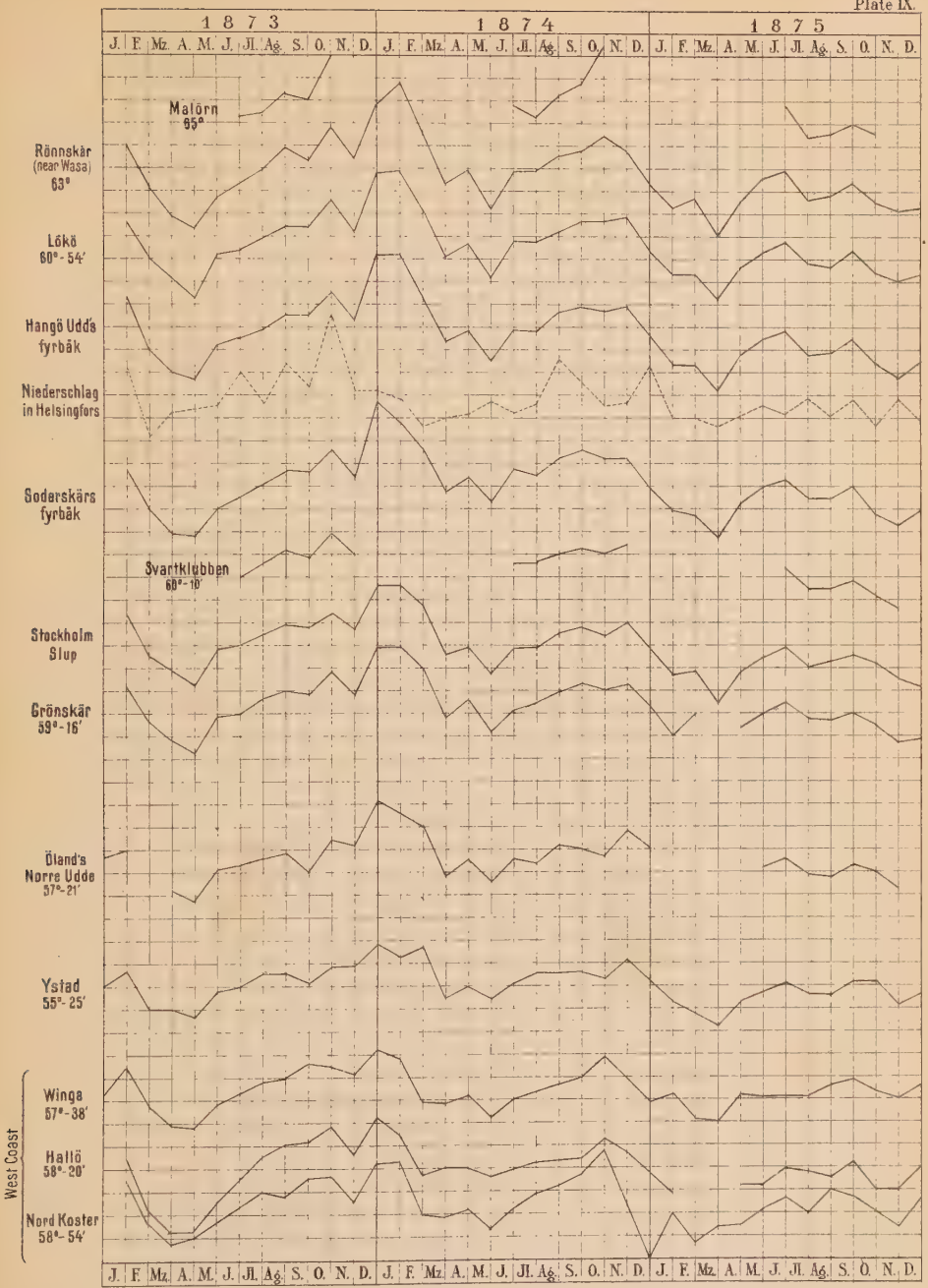
maximum of 1863, as well as the fall which occurred towards 1871, the high level of 1873, and especially of 1874, and finally the low level of 1875. The curves for the Cattegat are of less amplitude.

We obtain a much better conception of the whole when we take into account the observations made in Finland. Exceptional phenomena are of special importance, by reason both of the perturbation they introduce, and of the manner in which this perturbation is propagated. The most extreme of these perturbations was the great fall in the yearly mean level of 1874 to 1875; this I have attempted to represent on Plate III. The fall on the Finnish coast at Rönnskär (lat. 63° N.) amounted to 26·1 centimeters; at Lökö lotsplats (lat. 60° 54′ N.) to 26·2 cm.; at Utö lotsplats to 24·1 cm.; at Jungfrusunds lotsplats (lat. 59° 56′ N.) to 23·8 cm.; at Hangö Udd's inre lotsplats (lat. 59° 48′ N.) to 25 cm.; at Hangö Udd's fyrbåk, at the entrance to the gulf of Finland, to 26·1 cm.; at Porkala lotsplats to 25·5 cm.; and at Söderskärs fyrbåk to 24 cm. The northern stations of Sweden are, as we have seen, summer stations, but the broken curves given on Plate III for Malörn (lat. 65° N.) and Svartklubben (lat. 60° 10′ N.) show that this group of stations reveals quite analogous movements, though they do not embrace either the maxima or minima. This deficiency is sufficient by itself to render them useless for the determination of a mean.

These means gave a fall of 26·7 cm. for Malörn in 1875, and for all other stations of over 20 cm.; the lock of Stockholm gave 22 cm. At the other stations along the Swedish coast the records are broken, strange to say, just at the minimum which occurred in April, 1875, as though the apparatus had been inadequate to record so unusual a fall (Grönskär, Öland's Norre Udde, also Hallö in the Cattegat; Utklippan is only a summer station). Ystad showed only 13·9 cm., Swinemünde 4·88 cm., Travemünde 5·75 cm., Winga in the Cattegat (lat. 57° 38′ N.) 5·3 cm., Nord Koster (lat. 58° 54′ N.) somewhat higher, 8·0 cm., due probably to the influence of the Norwegian rivers.

These data reveal the wide distribution of the disturbance and at the same time its progressive exhaustion towards the south. The latter character plainly displays itself in the contrast between the steep curves of the north (Plate III) and of the whole coast of Finland to Söderskärs fyrbåk, and the much flatter curves of Ystad or the Cattegat.

Further, a curve is given on Plate III, next to that plotted from Moberg's figures for Hangö Udd's fyrbåk (1873 to 1875), to show the rainfall at Helsingfors according to the tables of Borenius. It will be seen that in 1873 the minimum rainfall of February was not followed by the minimum of level till March and April; next, in October, 1873, there was an unusually heavy rainfall of 139 mm., the effect of which was first manifested as a high level in December and January, and subsequently,



The Monthly Mean Water-level for the Years 1873, 1874 and 1875 from Rönnskär to Nord Koster.

A. Haase, Prague, Lithographer to the Imp. a Roy. Court.

as the water flowed away, in a reduced minimum for 1874; and thus it happened that in 1874 the minimum rainfall of February was not followed till May by a minimum level, and then only by an exceptionally feeble one; at the same time the mean level for 1874 was unusually high, and indeed somewhat higher than that for 1873, the year in which the great rainfall of October had occurred. In January, 1875, the curves for rainfall and water level were both low; the minimum followed in March, but the low value of the mean level for 1875 did not result from this minimum, but from the very small amount of rainfall and the very low level of water during the whole summer, autumn, and winter of 1875.

The drop in the annual curves from 1874 to 1875 is thus no doubt dependent on the rainfall; but it is precisely with this drop that Forssman's curves happen to end, and consequently the mean value of the negative displacement as calculated by him is much too high.

It is believed that the annual means for 1852 to 1875 furnish evidence of a general negative movement of the strand-line. This is no doubt the case; but if we divide the twenty-four yearly means into six groups of four years each, we shall find a negative value for the first, a positive for the second, and negative values for the remaining four groups.

Thus, in addition to the seasonal oscillations revealed by the monthly means, there are others of greater amplitude and longer period. Although we have no correspondingly long series of observations in the case of lake Ladoga, yet, according to Tillo and Woeikof, oscillations of long duration occur here also; and in this connexion attention may be called to the fact that the Neva alone contributes to the Baltic region an annual supply of fresh water estimated to amount to about 94 cubic kilometers [1].

Such, then, is *the nature of the movement of the strand-line* in the Baltic. Apart from local or temporary influences, such as atmospheric pressure, the driving force of the wind, and direct radiation from the sun, there is, on the one hand, *a seasonal oscillation*, largely dependent on rainfall and thaw, and on the other *an oscillation of longer period affecting the successive annual means*, and characterized *at the present day* by a preponderant, though not constant, negative value. Further, the oscillations have a larger amplitude in the north than in the south.

It may be observed that the method of comparison hitherto employed is not well adapted to the purposes of this inquiry, since the means are given for the calendar years, and these embrace the second half of one maximum and the first half of the next succeeding. Thus, as may be seen from Plate III, the yearly mean for 1874 includes two maxima, one

[1] A. Woeikof, Les Rivières et les lacs de la Russie, Arch. sci. phys. et nat. Genève, 1885, 3e sér., XIII, p. 45 et seq.; A. von Tillo, Die Meereshöhe der Seen Ladoga, Onega und Ilmen, und das Gefälle des Ladoga-Sees, Bull. Acad. Imp. Sci. Saint-Pétersb., 1886, XXX, pp. 445–448.

for 1873 to 1874, and the other for 1874 to 1875, and in the northern stations this is especially marked. Woeikof's annual means for lake Ladoga are calculated by phases, i.e. from June to May.

The uniformity now known to characterize the oscillations lends increased importance to the long series of exact observations made since 1825 at the lock of Stockholm. In this series, also, we perceive an alternation of positive and negative signs, but on the whole the negative values are slightly in excess. Thus out of the fifty differences between the fifty-one annual means from 1825 to 1875 we find twenty-three positive and twenty-four negative; and three times only have the successive annual means been equal. The sum of the twenty-three upward displacements amounts to +142 cm., of the twenty-four downward displacements to −189 cm.; there thus remains a negative excess of −47 cm. But this is only the difference between the two mean levels of 1825 and 1875. If, as Forssman has done, we apply to the whole series of observations a rectilinear equation, and then proceed according to the method of least squares, the difference is reduced from −47 to −18·7 cm., and this result again is affected by the exceptional minimum of 1875.

These considerations show with what caution those data must be used which rest only on occasional observations of marks cut in the rocks. The value attaching to observations of this kind, however, lies in the great length of the periods they embrace, since they indicate the positive or negative character of the excess which remains after addition of the movements of opposite signs, but the precise value of this excess cannot be determined from them.

4. *General account of the negative displacement.* We will now attempt to give a general account of the observations so far as they have been recorded up to the present time; we shall consider the records both of the stations where daily observations are made and of the summer stations in the north; and as well the isolated observations on marks, making use for this purpose of the information so kindly provided by Dr. Holmström; we shall also take into account the results obtained in Norway and Finland. The average negative displacement which may be deduced for each year, on the assumption that the movement is uniform, will be given in centimeters and enclosed in parentheses.

In 1839, at the suggestion of Schive, a number of places on the coast of Norway were provided with marks, and in 1865 Roll concluded from the marks on the southern part of the coast that the mean level had risen. The marks on the Atlantic coast, owing to the great range of the tides, yielded no results of any value, but at each of the seventeen stations between Stavanger and Moss, or along the whole north coast of the Skager Rack, a fairly marked negative displacement was indicated; it amounted on the whole to 7 or 8 cm. in twenty-six years (about 0·3). Roll, however, expressly

states that the number of observations was too small to give any real importance to this result [1].

On the east coast of the Cattegat are situated the three stations of continuous observation, Nord Koster, Hallö, and Winga, previously mentioned; reference has already been made to the correspondence of the oscillations recorded by them with those on the Swedish coast of the Baltic during the period 1825 to 1875. Some earlier marks also occur on this coast, and Holmström obtained fresh measurements from them in 1886; according to his observations the results for 1847 to 1866 may be regarded as trustworthy, and for this period a negative displacement of 15 to 20 cm. (0·4–0·5) is found. The oldest mark on this coast was set up by Cronstrand at Marstrand in the year 1770; it has often served as a reference. This gives for 1770 to 1866 a negative movement of about 55 ? cm. (0·47 ?) [2]. On the Väderöarne (lat. 58° 35′ N.), situated at some distance from the coast, special conditions seem to be dominant. Forsell established a mark in 1804; Lovén in 1850 found −59·5 ? (1·3 ?), and later measurements by Holmström gave for 1850 to 1867 −13·5 cm. (0·79), and for 1867 to 1886 −13·5 cm. (0·7), indicating a greater negative displacement than at the neighbouring stations. In this locality, Fjällbacka, a place already mentioned, is situated, and in its harbour the rock of Gudmundskäret, to which Linnaeus appealed in proof of emergence. In 1532 this rock was covered by the sea; in 1662 it projected a little, but its exposed summit was then so small that it could be covered with a hat; in 1867 Holmström found that it had attained a height of about 131 cm. above the tang-line. This is certainly the most striking example on the whole coast of Sweden.

Dr. Holmström points out that a perpendicular cliff, 250 feet high, rises above Fjällbacka; it is traversed by a fissure about 2 meters wide, opening down to a great depth, and certainly more recent than the glacial deposits which crown its summit. This, he considers, indicates a dislocation still in progress within the mountain mass, and furnishes an explanation of the local inequality in the movement of the strand-line.

The fact may be recalled that it was precisely in the neighbourhood of these islands, distinguished by so marked a negative movement, that Ekman encountered waters of different composition; a slight change in the prevailing course of the currents might in course of time have helped to increase the differences.

Near Varberg (lat. 57° 6′ N.) we reach the last point at which measurements have been made on this coast; and no data have been obtained from

[1] Roll, Vandstandsobservationer, udgivet af den norske Gradmaalingskommission, I. Heft, 4to, Christiania, 1882, p. 9.

[2] Two lines exist from 1770, the significance of which is not quite clear; I follow Holmström's interpretation.

Scania. The little island of Saltholm, near Copenhagen, has long been cited as a proof of the constancy of the sea-level; it is submerged in autumn and winter, and dry only in summer, and thus lies within the limit of the annual oscillations; yet we find it mentioned as early as the year 1280[1]. I am not aware of any recent examination into the facts; but it may be pointed out that the southern entrance of the Sound and the Sound itself act towards the outflow of the Baltic in the same way as the opening in a dam, and conditions other than those of an open basin, dependent on the pressure and velocity of the discharge, determine the vertical height of the issuing water. Passing disturbances, such as storms, are lost for the greater part in the averages on which the curves are based; by these curves the correspondence between the oscillations on the east coast and the west is brought to light, and by them also it is shown that the oscillations must necessarily be propagated through the Sound, even if they do not continue to maintain the same amplitude.

The accounts at my disposal with regard to Ystad are contradictory; on the coast of Blekingen a negative displacement of unknown amount occurs. As to Skallö, near Kalmar (lat. 56° 41′ N.), we learn that Wikström, after making daily observations for many years with a view to determining the mean level, placed a mark here in 1760; subsequently Frigelius in 1802, and Siljeström in 1844, found that the mean level almost exactly coincided with the ancient mark. It is, perhaps, hard to say whether the conditions which prevail in the narrow strait of Kalmar resemble those which seem to exist in the Belt, or what other significance must be assigned to these ancient observations; it is certain that Holmström found a negative movement here also to the extent of 17 cm. from 1844 to 1886 (0·4). The values found by Forssman for Utklippan (0·67), a summer station in lat. 55° 57′ N., and for Oeland's Norre Udde (0·23) in lat. 57° 22′ N., from the period 1852 to 1875, I will not venture to compare with Holmström's results, since they were obtained by calculation.

Towards the north, as far as Landsort (lat. 58° 45′ N.), there was formerly a general negative movement, but at the last-named place it has been thought that of late years signs of a positive movement are to be found; the facts, however, are not definitely established.

Stockholm (lat. 59° 19′ N.) has already been discussed; the neighbouring stations, Grönskär (lat. 59° 17′ N.) and Vedlösa (lat. 59° 51′ N.), give results which correspond completely with those of Stockholm. According to Nordenskiöld and Forssman the movement at Stockholm from 1774 to 1825 amounted to −30 cm. (0·59), from 1825 to 1852 to −11 cm. (0·41), and from 1852 to 1875 to −8 cm. (0·32), or altogether to −49 cm. in 101 years (0·49).

[1] K. von Hoff, Geschichte der natürlichen Veränderungen, I, p. 439; Lyell, Principles, 11th ed., II, p. 181 et passim.

Further north on the Swedish coast we have now only marks and summer stations. At Djursten's fyr (lat. 60° 22′ N.), Forssman calculates for 1852 to 1875 only −3 cm. (0·13); this point lies just above the sea of Åland, but calculations based on the observations of summer stations cannot be used for comparison. Whether this deep is a colk, perhaps caused by ice, is a question that might be worth investigation. From this locality the extent of the negative movement appears to increase towards the north. At Löfgrundet (lat. 60° 45′ N.), where a mark exists made by Rudman in the year 1731, the movement has already become considerable; it is particularly well marked in latitudes 63° and 64° N., amounting to more than 1·0 cm. in a year, but since 1850 there has been a falling off. The largest total difference is shown by the rock in Ratan (lat. 64° N.) marked by Hellant; this gives −123 cm. for the period 1749 to 1869, or in 120 years. Here we are already within the Quarken. In Storebben (lat. 65° 15′ N.) another mark was set up by Hellant in 1750; the observations may be interpreted in two ways, giving for the interval 1750 to 1869 either −122 cm. (1·02) or −155 cm. (1·3). In any case, the movement at this point is very considerable, but here again the readings show a falling off during the last few decades. Malörn's fyr (lat. 65° 32′ N.) has only been under observation since 1852; the displacement calculated by Forssman is only −8 cm. (0·32).

On the west coast of Finland, Holmström lays special stress on the marks erected by Klinzius in 1755 at Bergö (Vargö, lat. 63° N.) and Rönnskär (30 kilometers further to the north-west); they indicate a particularly uniform movement; thus the record of Bergö gives from 1755 to 1785, according to Schultén, −43 cm. (1·43), from 1785 to 1797, according to C. P. Hallström, −12 cm. (1·20), from 1797 to 1821, according to Brodd, −35 cm. (1·46), and from 1821 to 1852, according to Stjerncreutz, −11·5 cm. (0·35); or in all from 1755 to 1852 a movement of −96·5 cm. (1·0). The record of Rönnskär from 1755 to 1797 is, according to Hallström, −50·5 cm. (1·20), and from 1797 to 1821, according to Brodd, −34·5 cm. (1·44).

At the castle of Åbo (lat. 60° 25′ N.) Gadolin determined the water-level in 1750; in 1841 it stood 52·5 cm. lower (0·57). Judging from the observations for 1858 to 1872 and the position of the ancient marks, Moberg in 1873 concluded that a movement of 59·67 cm. in the century had occurred. The steep, but yet uniform, curves obtained for Finland from the observations made since that date have already been referred to.

Moberg's observations were made not only on the west coast of Finland, but also over a large part of the north coast of the gulf of Finland. At the head of the gulf, near the château of Monplaisir, not far from Peterhof, F. Schmidt found distinct traces of a negative movement, and others not quite so evident near castle Tolsburg, not far from port Kunda on the south

coast of the gulf. On the other hand, the east coast of Oesel has not furnished any definite evidence[1].

Further south the movement appears to decrease, and after much fluctuation of opinion it is now agreed that the long-continued observations on the German coasts prove that in course of time the secondary oscillations completely balance each other, and consequently that there is no continuous movement of the mean level either in a positive or a negative direction.

Thus, then, in Sweden and Finland there is everywhere negative movement along the coast, but it was more marked in the eighteenth century than the ninteenth. Still, even where it attained its highest value, and where the evidence can be traced back for over a century, it does not amount to more than −123 cm. (Ratan, lat. 64° N.), or perhaps −155 cm. (Storebben, lat. 65° 15′ N.); to these loci of maximum movement we may add Gudmundskäret near the Fjällbacka in the Cattegat, with a probable value of −150 cm., but this displacement may stand in some connexion with local conditions.

It is in the north that the indications are most strongly marked. At Stockholm the negative movement may still be clearly perceived, but it is not so great as on the opposite coast at the entrance of the gulf of Finland, whence so much fresh water is discharged. The movement is continued along the coast of Sweden, with an unexplained interruption at Calmar, which occurred during the earlier years of observation. It extends to beyond Carlskrona, but from the south accounts are defective or uncertain. In the Sound it seems to be far feebler; then it reappears and continues with great uniformity, though in diminished amount (except on the Väderöarne), along the coast of the Cattegat, always accompanying the outflow from the Baltic; obscure traces of the movement also occur along the south coast of Norway to beyond Lindesnäs and towards Stavanger, or as far as the less saline water of the Baltic can be traced as an independent current.

On the opposite coasts of Denmark and Germany not a sign of this movement is to be detected; in this region a freer interchange of water takes place through the Belts; as far as Pillau the Baltic stands at the same level as the Ocean, and no movement, negative or positive, is to be discerned.

The question now arises whether it is possible to discover a *chronological limit* to this great process. Browallius cites against Celsius the fact that in west Finland very aged trees are to be seen at a trifling height above the sea: the numbers he gives are taken from an account by Gadd. A pine, 310 years old, was to be seen at Biernö, rooted two yards above the surface of the water; if the sea, Browallius remarks, actually sinks forty-five inches in

[1] F. Schmidt, Einige Mittheilungen über die gegenwärtigen Kenntnisse der glacialen und post-glacialen Bildungen im silurischen Gebiet von Esthland, Oesel und Ingermanland; Zeitschr. deutsch. geol. Ges., 1884, XXXVI, p. 272.

a century, then this tree must have been seated under water for 220 years; similar conclusions were obtained from a pine near Hitis in the Kirchen sund, 282 years old, one yard above the water, oaks 300 years old, three yards above it, and from other examples[1]. Although the measurements of the height above the water are evidently only approximate, yet they give fairly exact information as to a fact of great importance. The observations have never been disputed; on the contrary, Lyell himself affirms that he has seen extremely ancient oaks near Stockholm only eight feet above the water[2]. Högbohm has made measurements bearing on the question in Westerbotten, a part of the Swedish coast where the movement is greatest. Here in sheltered spots the sea is bordered by a bare strip of land, which marks the limit of the yearly oscillation; above this comes a narrow belt of alders, then the fir woods. At Kallwiken, firs fifty-five to sixty years old stand three feet above the belt of alders. Assuming that the annual oscillations have remained the same, then the negative movement during the last fifty years cannot have amounted to more than three feet, i.e. 89 cm.[3] The readings from the marks lie within this limit.

Let us now return to the earlier observations, and take for example the years 1730 to 1740 as the mean date of the most important observations of Celsius, Linnaeus, and Browallius. At this epoch, Celsius estimated the negative movement at 4·5 feet in a century, or 1·33 cm. per year. The readings obtained from the rock of Ratan (lat. 64° N.) gave 1·14 cm. per year for the years 1749 to 1774, and those from the rock of Storebben (lat. 65° 15′ N.) gave 1·43 cm. for the years 1750 to 1785. On the west coast of Finland the displacement for about the same period should be 1·2 cm. There is thus a somewhat close correspondence with the estimate of Celsius. But it is impossible to reconcile the assumption of the persistence of this movement in the remote past with the observations of Browallius on the position of ancient trees. As early as 1700, Davidson established a mark in the north of the gulf; and in 1702 Hjärne published observations on a fall of the water level, which, according to contemporary accounts, must have been very striking; but during the last decennium of the nineteenth century a general falling off of this movement has made itself evident.

Thus it would appear that the movement was particularly rapid at the end of the seventeenth and the beginning of the eighteenth century, and is now diminishing.

The conclusions to which Grewingk was led as to the result of a study

[1] Browallius, Historische und physikalische Untersuchung, p. 241 et seq.

[2] C. Lyell, On the Proofs of a gradual Rising of the Land in the Central Parts of Sweden; Phil. Trans., 1835, CXXV, p. 13.

[3] A. G. Högbom, Om sekulära höjningen vid Vesterbottens Kust; Geol. Fören. Stockh. Förh., 1887, IX, pp. 19–25.

of some prehistoric remains are also worthy of consideration; they are by no means opposed to the existence of a negative movement, but are certainly inconsistent with the assumption of a constant rate. The signs of negative movement at castle Tolsburg, on the south side of the gulf of Finland, have already been mentioned. Not far above Tolsburg, however, there occurs at Kunda, 130 feet above the sea, a white calcareous marl, the deposit of a fresh-water lake, containing abundant remains of a tribe which lived by fishing and the chase, together with bones of a gigantic pike. The age of the settlement is estimated at about 2,000 years, but judging from the rate of negative movement now in progress on the coast of Finland, the lake of Kunda 2,000 years ago must have been submerged beneath the sea, and even if we take only half the present rate we obtain the same result. Rising near the river Salis, which flows from Bustneck into the gulf of Riga, is a hill known as the Rinne, an elongated mound of kitchen débris; this affords evidence against any considerable displacement of the strand-line, such as would result from the accumulated effects of centuries. On the other hand, judging from the presence of oysters in the kitchen middens, Baer has concluded that at the exits of the Baltic, particularly in Zealand and Funen, the sea was salter than at present. The castles of Werder (built 1284) and Arensberg (built 1221) give the impression, according to Grewingk, of a state of things which has suffered no appreciable change for many centuries[1].

Thus we arrive at the following results:—

The Baltic, together with the gulfs of Bothnia, Finland, and Riga, is supplied by numerous rivers with a vast volume of fresh water; its communication with the Ocean is more or less restricted; and it consequently possesses a very low degree of salinity. In its more remote parts the water is fresh enough to drink. Strong currents move from the inner gulfs towards the Baltic. In the Belts there are under-currents of salt water and upper currents of less salinity which flow outwards; salt water only exceptionally passes through the Sound into the Baltic. A stronger current of Baltic water proceeds from the Sound along the coasts of Scandinavia towards cape Lindesnäs and the Ocean.

The sea along the German coasts, except at Memel, stands at the same height as the Ocean; in the north no recent determinations of level have been made; the ancient observations show a considerably higher level of the water in the gulf of Finland, and a still higher in the gulf of Bothnia.

A negative movement now in progress may be traced from the wiek of Bothnia and the gulf of Finland, along the whole coast of Sweden as

[1] C. Grewingk, Die neolithischen Bewohner von Kunda in Esthland, Verh. geol.-esthnisch. Ges. Dorpat, 1884, XII, pp. 1–133, maps; K. von Baer, Ueber ein neues Project, Austernbänke an der russischen Ostseeküste anzulegen, Bull. Acad. Imp. Sci. Saint-Pétersb., 1862, IV, pp. 35–47.

far as the Skager Rack; it is perhaps continued along the coast of Norway to cape Lindesnäs and Stavanger. It follows the current of less saline water flowing out of the Baltic. On the coasts of Jutland and Germany there is no movement. In the narrow parts of the Sound it appears to be very inconsiderable.

The monthly means on the coast of Finland and the east coast of Sweden show an annually recurring oscillation. The rise of the curve is caused by the swelling of the rivers during the breaking up of the ice and the melting of the snow and the fall of rain. The same curve is given by the monthly means of the west coast, but with a somewhat later rise of less duration. Off the coast three layers of water may be distinguished—the uppermost, formed by the fresh water of the neighbouring rivers, as much as two fathoms in depth, beneath it the outflowing Baltic current, and below this again the heavier bottom water of the Cattegat.

The curves of the annual means for 1852 to 1875 reveal, according to Forssman, a remarkable correspondence between the oscillations of the east coast and those of the west, high yearly means on the east coast always corresponding to a high level on the west coast, and so on. The curves on the west coast are, however, not so steep as those on the east. At the Fjällbacka some local influence makes itself felt.

Judging from the evidence afforded by ancient trees, the negative movement must have been very pronounced towards the close of the seventeenth century; it continued through the eighteenth century, and is now diminishing. This negative phase can hardly have set in very much before the end of the seventeenth century.

The conclusion to be drawn from these facts is, in my opinion, that Nordenanker, Chambers, and Stjerncreutz have rightly interpreted this phenomenon. It is a question of climatology and hydrostatics, not of tectonic geology. That which happens is *an emptying out of the water, not a rise of the land.* Even if we were willing to concede so extensive an elevation of the lithosphere, we should still be unable to explain why this movement should be restricted solely to the region of the Swedish coast and of the outflowing Baltic current, while on those coasts where there is a more active interchange of water, i. e. the coasts of Denmark and Germany, it is absolutely imperceptible. The monthly means, with their seasonal variations, show in an irrefutable manner that the level of the water is dependent on the drainage from the land; and the annual means of the east and west coasts of Sweden reveal a uniformity in the continual oscillation of positive and negative displacements which is absolutely irreconcilable with movements of the lithosphere.

Nordenanker left unsolved the question whether the decrease in the volume of the water is due to diminution of the supply, or to an enlargement of the exits. If the latter were the case, then the volume of the

outflowing current should have increased at the mouth of the Sound; but it is decreasing, consequently there must be a decrease in the supply. The abatement of the negative movement now in progress ought to find expression in a gradual increase in the rainfall. Unfortunately we do not possess trustworthy data on which to base an inquiry as to a secular change of rainfall in this region. Rubenson finds that the older records kept at neighbouring localities are contradictory, and consequently useless. Blytt has been led by various considerations to conclude, and certainly with good reason, that Scandinavia has passed through great climatic changes, but we cannot determine with certainty the nature of the existing phase. The data bearing on the Scandinavian glaciers collected by Heim scarcely lead to any definite result. Svenonius has found traces of extinct pine forests at many places in Lapland; they occur even above the region of birches, and sometimes extend many miles beyond the existing pine forests of the present day. Places exist, which the Lapps call 'tsuoptsa,' where a large patch of snow lies from year to year: in the heat of summer the reindeer are driven to these spots. According to the statements of the Lapps the tsuoptsa have been gaining in size and number within the memory of man. It would seem, however, that certain climatic phases affect the entire globe[1].

The monthly oscillations attain their greatest range in the wiek of Bothnia, owing to the influx of fresh water which pours in from the east and west, and because the conditions are there least favourable to equalization. The negative movement, which is disclosed as the final result of the collective observations of a century, is strongest in the north because, under the conditions already described, the general slope of the Baltic waters has changed, and this finds its clearest expression in those parts which lie most remote from the exits. It was at one time believed that the elevation of the land continued to increase still further to the north, and was greatest at the North cape; but neither from the North cape nor from any other locality on the north and west coast of Norway do I know of any convincing proof of a negative movement at present in progress.

Special attention was directed to this absence of evidence by Erdmann and Lovén in 1850, when, in the remarkable treatise already mentioned, they prepared the way for the new system of measurements[2]. In their opinion the Baltic must certainly be regarded as an inland sea, in which the surplus of fresh water is obstructed in its outflow by land and islands,

[1] A. Blytt, On Variations of Climate in the course of Time, Christiania Vid. Selsk. Förh., 1886, No. 8, pp. 21-24, and in many other publications; A. Heim, Handbuch der Gletscherkunde, 8vo, Stuttgart, 1885, p. 517; Svenonius, Studier vid Svenska Jöklar, Sver. geol. Undersök., ser. C, No. 61 (and Geol. Fören. Stockh. Förh., 1884, No. 85, VII), pp. 1 to 36, map.

[2] Erdmann och Lovén, Öfvers. K. Vet. Akad. Förh., 1850, VII, p. 45.

and in which the level most probably does not coincide with that of the Ocean; they discuss the question of a decrease in the influx and of the slope, but conclude that the vast surface of the Baltic could scarcely be influenced by these factors to the extent indicated by the marks. Under any circumstances it is impossible to determine the extent to which the land is elevated, until the value of the possible fall of the water level is definitely known. The inequalities of the movement indicated by the ancient marks must be referred to movements of the land itself, and may perhaps stand in causal connexion with local earthquakes.

The results obtained by Dr. Holmström, to whom I am indebted for so much valuable information, tend in the same direction, but are much more definitely expressed. The displacements on the west coast of Sweden, as on the coast of Finland, correspond so closely that they can scarcely be referred to movements of the lithosphere. Yet certain facts are known on the west coast of Sweden (Fjällbacka) which render it probable that local dislocations of the earth's crust, perhaps of the nature of faults, also occur [1].

A local dislocation of this kind, whether it can be proved to exist at Fjällbacka or not, is a very different thing from that uniform elevation of the mainland extending to beyond the North cape which was imagined by von Buch, or from that tilting movement of the whole peninsula which Lyell thought he could recognize.

Thus, as regards *the general secular elevation of the Scandinavian peninsula, the source and origin of the theory of elevation, definite evidence is entirely wanting.* The uniformity of the oscillations, which, save for rare exceptions, is ever being rendered increasingly apparent by the recent

[1] With regard to a second case to be referred here, Dr. Holmström writes: 'Near Södra Stäcket (lat. 59° 18′ E., south-east of Stockholm) the Sound between Vermdön and the continent was cleared in 1704 to facilitate navigation. A mark was then carved on each side of the Sound *at the same height*, twelve feet above the surface of the water. In 1855 these marks were measured, and it was found that they were not at the same height, but one of them was 1·16 feet (34·5 cm.) higher than the other, the two marks standing respectively 14·95 and 13·79 feet above the surface of the water. A measurement made in 1879 gave the heights as 14·73 and 13·67 feet, i. e. a difference of 1·06 feet (31·5 cm.). The measurements of 1855 and 1879 are thus very nearly the same. If the measurements in 1704 were correct, then these two points, which are about 131 meters apart, must have been elevated unequally until 1855, i. e. the continent must have been raised 2·95 feet (87 cm.) and the island 1·79 feet (52·25 cm.) in the course of 151 years, or, on an average, 0·58 and 0·35 cm. annually. From 1855 to 1879, on the other hand, no change of importance took place in the relative position of the points, while their behaviour as regards the sea-level indicates a subsidence rather than an elevation. These remarkable observations on the unequal movement of points in such close proximity are so far unique. . . . No definite conclusion can be drawn from them.' In another passage Dr. Holmström discusses the possibility of a fault. Erdmann believes that an error was made in the original marking, and the probable source of the error is discussed by Börtzell in Öfvers. K. Vet. Akad., 1879, XXXVI, p. 87, note 2.

daily observations, shows that the facts observed may be much better explained by a diminution in the influx of this isolated basin, and the evident dependence of the greatest disturbances of the water level on exceptional variations in the rainfall clearly point in the same direction [1].

5. *Submerged forests and peat bogs of the North sea.* The English channel, that arm of the sea which separates England and France, is broad in the west and grows narrower towards the east. Its depth diminishes in the same direction, and near its narrowest part rises a submarine ridge. The flood tide sweeps strongly into the Channel from the west, and pours across the ridge into the North sea.

These facts led to the notion that the Channel itself was originally a bay opening to the west, and that the tide, assisted by storms, had destroyed a ridge of land which long ago united England with the continent. As early as 1717, Musgrave wrote: *Concludimus . . . Britanniam non iam inde ab initio fuisse insulam, sed ex paene-insula factam: idque ut videtur, a vento e saevioribus aliquo, cum maris aestu concurrente et isthmum perrumpente.* Buache shared this view, and Desmarets advocated it in an admirable treatise in 1751 [2].

The Baltic has already shown us how difficult it is to pronounce with certainty on events so remote, and also that a close examination of the actual facts may bring to light a far greater complexity than might at first have been expected. We have only to turn to the cliffs of Sangatte, near Calais, to perceive that manifold alternations have occurred in the present case also. At the top is a mixture of whole and broken flints in brown sand, some three to seven meters in thickness; it contains no fossils. Below is a bed fifteen to twenty meters thick, formed of chalk rubble with irregular intercalations of sand; this has afforded *Elephas primigenius, Succinea oblonga, Pupa, Helix,* and other fossils. We have here then a terrestrial formation, with somewhat of a Loess fauna, exposed in the cliffs along the coast and plainly indicating a former land connexion with England. Beneath this bed, however, we find, according to Robbe and Barrois, coarse marine sand with *Purpura lapillus, Littorina littorea, Tellina baltica,* and other species characteristic of the existing fauna of the North sea. From this we must conclude that this region was occupied by the sea before the land communication was established; and we may

[1] E. Brückner has recently come to the same conclusion; Die Naturforscher, published by O. Schumann, 4to, Tübingen, 1887, pp. 291–293.

[2] W. Musgrave, De Britannia quondam paene Insula Dissertatio, Phil. Trans., London, 1717, XXX, pp. 589–632; N. Desmarets, L'Ancienne Jonction de l'Angleterre à la France, ou le Détroit de Calais, sa formation par la rupture de l'isthme, &c., Ouvr. cour. par l'Acad. d'Amiens en l'année 1751; reprinted by MacKean & Co., 8vo, Paris, 1875, map.

observe in passing that the succession exposed here shows that the existing marine fauna is older than the Mammoth [1].

Ancient tradition throws no light on the circumstances which led to the isolation of Britain, for Vergil's often quoted words, *Penitus toto divisos orbe Britannos*, can scarcely be regarded as evidence. It is well known also that about the year 330 B.C. Pytheas of Massilia sailed through the Channel. On the other hand, Nilsson thought he could recognize, in the more important cases of inbreak and destruction on the coasts of the North sea, traces of the Cimbric flood mentioned by many authors of antiquity; this catastrophe, which occurred somewhere about 360 to 350 B.C., is said to have driven the Cimbrians to seek new dwelling-places, as Florus writes: *quum terras eorum Oceanus inundasset* [2]. Many subsequent observers have supported Nilsson in this conjecture. England, Holland, and the west of Denmark furnish us, however, with many records relating to violent floods and irruptions of the sea which have occurred since that time, and of which some traces still exist. They have sometimes assumed the character of true deluges; thus the flood of 1277, which gave rise to the Dollart at the mouth of the Ems, destroyed forty-three parishes and caused the death of 80,000 persons in Friesland; or, again, the *grosse Mandrankel* (great drowning of men) of September 8, 1362, which engulfed thirty parishes, and tore away great parts of the islands of Sylt and Föhr. The great flood of Christmas, 1717, drowned, according to the statements of *Arends* and *Eilker*, 10,828 persons and 90,000 head of cattle. Such numbers recall the terrible catastrophes in India [3].

As regards the Zuyder Zee, Bakhuyzen and Pleyte give us the following information:—The Flevus of Roman authors branched off from the Rhine near Wageningen, below Arnheim, flowed through the bed of the Eem to the Lacus Flevus, which consequently formed a part of the later Zuyder Zee,

[1] C. Barrois, Note sur la faune quaternaire de Sangatte; Ann. Soc. géol. du Nord, 1880, pp. 181–183.

[2] Nilsson, Skandinaviska Nordens Ur-Invånare, I, Lund, 1838–1843, pp. 89–92, and Skandinavisk fauna, Dägsdjur, 2. uppl., 1847, Introduction, p. ix; Maak, Die Dünen Jütlands, Zeitschr. f. allg. Erdkunde, Berlin, 1865, Neue Folge, XIX, pp. 204 et seq.; M. W. Fack, Die cimbrische Fluth in ihrer Einwirkung auf den Boden von Kiel, Mitth. naturw. Ver. Kiel, 1868, IX, &c. Tardy goes much further and attempts to prove that opposite movements took place in the ninth century in the Flemish peat bogs and the buildings of Theodorich at Ravenna; he even discovers a great flood in the twenty-third century B.C., and identifies it with the Mosaic flood; Comparaison entre deux oscillations contemporaines, Bull. Soc. géol. de Fr., 1874, 3e sér., II, p. 222; 1876, 3e sér., IV, pp. 326–329; and 1878, 3e sér., VI, pp. 148–151.

[3] For a list of ancient floods see Dumas-Vence, Notice sur les côtes de la Manche et de la mer du Nord, Revue coloniale et maritime, Paris, 1876, XLVIII, p. 395 et seq.; for the east see A. Baudissin, Blicke in die Zukunft der nordfriesischen Inseln, 8vo, Schleswig, 1867, pp. 55–78 et passim; G. Eilker, Die Sturmfluthen in der Ostsee, 8vo, Emden, 1877, p. 4 et seq.; also p. 65 et seq., the history of the formation of the Dollart.

and then discharged into the sea between Vlieland and Terschelling. The enlargement of the Lacus Flevus proceeded bit by bit, and was certainly far from complete in the year 1400. The remains of Roman constructions are situated about ten minutes' walk beyond the dunes, near the mouth of the Scheldt in Walcheren, near the mouth of the Meuse in Goedereede, near the Altrhein at Katwijk, on the shores of the Flevus (Vlie), and elsewhere. They are sometimes visible at very low water, showing that the dunes have advanced further inland [1].

It is well known that in the course of years the wind and sea slowly build up littoral embankments or bars, and that then the sea from time to time breaks through them in a devastating irruption, again taking possession of long tracts of the newly-formed land. With the knowledge of these facts, however, a theory has arisen that oscillations of the solid land have also occurred, and in support of this, attention is called to the beds of shells, which indicate negative movement in prehistoric times, or as still more convincing, the fact that at many parts of the coasts in question forests and peat bogs, sometimes even a repeated alternation of peat and marine sands, are now found lying beneath the level of the sea. Thus, in 1849, Godwin-Austen, with a view to showing that the English channel owes its origin to a subsidence of the earth's crust, elaborated a map on which he indicated the numerous points at which, even at that early date, forests and peat bogs were known to occur beneath the sea [2]. In 1872 Delesse expressed the opinion that the apparent subsidence of the coast of the Netherlands was a result of the pressure exerted on the underlying Tertiary clays by the gradual accumulation of alluvium [3]. But this conjecture, as will appear directly, is not in harmony with the actual facts. The phenomena, even at the present day, are still frequently regarded as proofs of the subsidence of the lithosphere: they therefore demand a searching examination.

It may be observed, to begin with, that these bogs and forests are much more recent than the Sangatte beds mentioned above. They contain Neolithic remains, numerous relics of the Bronze age, and sometimes even traces of the Roman occupation. Worsaae, who has accomplished so much in the study of this material, has called attention to the frequent presence in the bogs of beautiful bronze vessels and other objects which have been broken intentionally, and of swords also which appear to have been softened and bent in the fire, as though they were votive offerings, rendered useless

[1] Bakhuyzen et Pleyte, Lettre à M. Faye; Compt. rend., Paris, 1883, XCVII, 1, pp. 727, 728.

[2] R. A. C. Austen, On the Valley of the English Channel; Quart. Journ. Geol. Soc., 1850, VI, pp. 69–97, map.

[3] Delesse, Les Oscillations des côtes de la France; Bull. Soc. géogr., 1872, 6e sér., III, p. 14.

for secular purposes. As regards the submerged forests, Nathorst has shown that on the coasts of the Baltic, as in western Holstein and the Netherlands, they afford birch, fir, oak, and hazel, but never beech, which, as is well known, was the last tree to establish itself in Denmark and Scandinavia [1].

Starting from Normandy these bogs and forests extend along the north coast of Europe to Denmark, and they also occur at several localities in the south part of the Baltic; they are likewise visible at very many places on the coasts of England and Ireland. The submerged bogs are frequently continued inland with an upward slope and rise above the sea. The depth to which they are known to extend below the sea-level is, as a rule, very inconsiderable, and seldom amounts to as much as eight or nine meters.

To rightly interpret them we must first turn our attention not to submerged but existing peat bogs.

The mode of formation of lake bogs on the west coast of Schleswig Holstein has been described by Maack. First of all, aquatic plants establish themselves, such as Potamogeton, Nymphaea, and most important, *Stratiotes aloides*. Their leaves form a thick coating on the surface of the water, but this disappears in autumn. Next, however, a mantle of mosses begins to form, and persists through the winter, increasing year by year in thickness. This becomes overgrown by cranberry bushes (*Vaccinium oxycoccus*), and at length the alders root themselves in it. Thus the mantle of peat moss floats on the water of the bog. Such an *unripe* bog consists of a layer of peat at the bottom, then the water of the bog, and a growing layer of peat moss at the top. Not until the upper and bottom layer of peat meet together is the bog *ripe* [2].

Forchhammer gives a similar description; he speaks of the unripe or quaking bog, which will scarcely bear the weight of a man, as a *hammock* (Bängesäcke) or see-saw (Schaukeln) [3]. We might almost imagine we had here a reminiscence of the description written long ago by the unknown author of the panegyric on Constantius Caesar: *Quamquam illa regio divinis expeditionibus tuis, Caesar, vindicata atque purgata, quam obliquis meatibus Vahalis interfluit quamque divortio sui Rhenus amplectitur,*

[1] J. J. A. Worsaee, Sur quelques trouvailles de l'âge de bronze faites dans les tourbières, Mém. Soc. roy. des Antiquaires du Nord, Copenhague, 1866, pp. 61 75; G. A. Nathorst, Om Skånes Nivåförändringar, Geol. Fören. Stockh. Förh., 1874, I, pp. 281–294.

[2] Von Maack, Das urgeschichtliche schleswig-holsteinische Land; Zeitschr. allg. Erdkunde, Berlin, 1860, Neue Folge, VIII, pp. 1–30 and 112–140, map; in particular pp. 9, 14 et seq.

[3] G. Forchhammer, Om den forandrede Vandhöide ved de danske Kyster; Nord. Univ. Tidsskrift, Kjöbenh., 1856, 2. Aarg., pp. 1–23, in particular p. 7; trans. into German by Sebald in Zeitschr. allg. Erdkunde, Berlin, 1856, Neue Folge, I, pp. 473–490, in particular p. 478.

paene, ut cum verbi periculo loquar, terra non est; ita penitus aquis imbuta permaduit ut non solum qua manifeste palustris est cedat ad nisum et hauriat pressa vestigium, sed etiam ubi paulo videtur firmior pedum pulsu temptata quatiatur et sentire se procul mota pondus testetur. . . .[1]

The Romans met with land of this kind on the lower Rhine. The effects of an irruption of the sea into such a region may be easily conceived. Even ripe bogs, however, contain a good deal of water, and it is well known that when they are subjected to artificial drainage their surface is considerably lowered. Skertchly has published some instructive data as to this from the peat bogs of the Fenlands in the east of England. The peat beds are in this case formed by Hypnum: Sphagnum is wholly absent; several successive forests are to be seen one above the other, and some of the buried trunks belonged to trees of a century's growth or more. Draining produces great subsidence of these bogs; thus a part of Whittlesey mere, 5·5 meters in thickness, sank between the years 1848 and 1875 to the extent of 2·36 meters, losing not much less than half its thickness[2].

This tendency to sink after drainage is not confined, however, to peat bogs; it affects also loose sediments saturated with water, such as occur behind the littoral bars and beaches, and the drainage of such land is thus sometimes beset with difficulties of a special character. In the Dutch polder farming the land is divided up into strips by long dykes and drained by canals. The water of the lagoons flows away to the level of low tide; where the range of the tides is considerable, the land readily sinks below the level of high water, and it requires careful management of the sluices to prevent this. For want of this precaution the work of drainage begun in the Lincolnshire Fens in 1814 at length reduced the land to so low a level that it became permanently submerged, and somewhat heavy showers of rain never succeeded in finding an outlet; consequently in 1867 it was found necessary to resort to pumping. Similarly Count Coronini describes the result of an attempt to drain the marshes of Aquilegia. In 1765 four great polders with sluices were established, 4,410 yokes of land were thus reclaimed, and the sanitary condition of Aquilegia was improved. This happy state of things did not last more than twenty years. All the district has again returned to marsh with an average level

[1] Incerti Panegyricus Constantio Caes. dictus, VIII. I write *Vahalis* after the ed. Baehrens; Gosselet and Rigaux quote the same passage and write *Scaldis*, following the Codex Vaticanus, 1775; J. Gosselet et H. Rigaux, Mouvement du sol de la Flandre depuis les temps géologiques, Ann. Soc. géol. du Nord, 1878, V, pp. 218–226.

[2] Sydney B. J. Skertchly, The Geology of the Fenland; Mem. Geol. Surv., London, 1877, in particular pp. 154–157; also Dalton, Subsidence in East Essex, Geol. Mag., 1876, 2nd Ser., III, pp. 491–493, &c.

of 0·79 meter below the high tide at normal springs, and of 0·16 meter only above the low tide during neaps[1].

There is yet another way in which peat bogs may subside, and to even a still more considerable extent; this is by the yielding of their foundation.

Let us cast a glance at the picture given by Seelheim of the state of things in the Netherlands. The peat bed at the mouths of the Scheldt is a single layer, 0·75 to 2 meters thick, formed of marsh plants. It is found over the whole of Walcheren, in south Beveland and Tholen, and on the Flemish coast. It occurs at many places on the low coast of the Netherlands, but chiefly about existing or ancient river mouths. In the islands of Zealand it seems at first sight to be horizontal, but on closer examination proves to have the form of a flat dome, being from 0·5 to 1·5 meters higher in the middle of the island than on the shores, where its surface lies from 1·0 to 1·5 meters below mean tide, and only at a few places reaches 0·3 to 0·4 meter above low tide. No doubt there has been subsidence, Seelheim remarks, but it has been caused by the caving in and lateral escape of the underlying sand. It is in consequence of this that the peat bed of the islands possesses a convex surface, and is traversed by fissures filled with dykes of sandy clay 'as if it had had to act like a mantle holding the masses of sand together[2].'

The folds in the peat beds of the Fens, figured by Skertchly, are probably to be explained in the same way.

In front, both of the Frische Nehrung and the coast of Pomerania, the trunks of trees may be seen standing rooted in their natural position down to six feet below the level of the sea. In the autumn of 1828, according to Hagen's account, the shore in the vicinity of the former communication of the Frische Haff with the gulf of Danzig was violently attacked by the sea, and in those places where the dune sand was washed away numerous roots and erect stumps of silver beech were to be seen at the level of mean tide. Hagen supposes that the peat in the neighbourhood of the sea previously stood at a somewhat higher level, and was overgrown with silver beech; the weight of dune, in its advance towards the interior, brought about a subsidence of the underlying soil[3].

[1] F. Graf Coronini, Ueber Boden-Meliorationen in Görz; Komers, Jahrb. österr. Landwirthe, Prag, 1870, X, pp. 192–206, in particular p. 199.

[2] F. Seelheim, Beitrag zur Entstehungsgeschichte der Niederlande; Verh. naturh. Ver. preuss. Rheinl., Bonn, 1885, 5. Folge, II, pp. 381–403, pl. Seelheim has encountered colonies of Phragmites in waters which contained more than 30 per cent. of salt water; see his Sur les tourbières d'eau saumâtre, Arch. Néerland., 1878, XIII, pp. 465–477. On the other hand Vélain found *Cardium edule*, *Cardium rusticum*, and Solen living in water so fresh that the ship was able to use it for drinking water; Bull. Soc. géol. de Fr., 1878, 3e sér., VI, p. 197.

[3] G. Hagen, Die preussische Ostseeküste in Betreff der Frage ob dieselbe eine Hebung oder Senkung erkennen lässt; Abh. k. Akad. Wiss. Berlin, math. Abth., 1865, pp. 21–41.

Even from the little island of Gotska Sandö, north of Gothland, an illustration has been given by Eisen and Stuxberg of a forest which has thus been overwhelmed by the sand[1].

We recognize, then, three different ways in which subsidence may take place, all of them depending on the nature of the bogs. Drainage, doubtless, seldom occurs in nature, and in any case only within the littoral embankments; isolated instances are, however, known in which a quaking bog has slowly lost its water by permeation through adjacent sands, and thus drained itself and subsided[2]. The caving in of the sand of the islands occurs within areas lately invaded by the sea. The bogs and forests forced downwards by the migration of the dunes are found on the outer side of these moving sands. It is unquestionably true that in England we often find above the peat a clay characterized by *Scrobicularia piperata*, which only thrives in brackish water, or, as sometimes happens, sand with *Tellina baltica*, and indeed such beds not uncommonly occur in repeated alternation with the peat[3]. It is also true that examples of this alternation are likewise known in France, and that in the Wattenmeer of Holstein the bogs, indeed even the quaking bogs, are covered with a layer of mud often of considerable thickness. But the most distinguished geologists of the Netherlands, who have before their eyes the most impressive results of the later incursions of the sea, have nevertheless not found in the situation of their peat bogs any evidence of oscillations of the earth's crust; they have seen in these simply and solely phenomena of the surface. In other lands observers have not been wanting who have regarded all these alternations of strata as a proof of so many elevations and subsidences, often repeated, affecting the whole rocky crust of the planet to a corresponding number of centimeters; thus, in particular, they have inferred from the submerged peat bogs a great and general subsidence of all the coastal region of the North sea before or during the Bronze age.

The following facts, however, must not be overlooked:—

(*a*) There are many localities on the coasts of the North sea where it may be directly shown that the height of the strand has remained unchanged for a period of greater or less duration.

At the great sluices of Amsterdam the sea-level has been continuously observed for centuries, and according to Bakhuyzen its constancy for

[1] Eisen O. Stuxberg, Om Gotska Sandön; Öfvers. K. Vet. Akad. Förh., 1868, pl. V, fig. 2.

[2] E. g. the Wilstermarsch; Maack, Das urgeschichtliche schleswig-holsteinische Land, p. 14.

[3] E. g. C. E. Rance, On the post-glacial Deposits of West Lancashire and Cheshire, Quart. Journ. Geol. Soc., 1870, XXVI, pp. 665-668; p. 659, from above downwards: 2-4 feet of sand with *Bithynia tentaculata*, 1 foot peat, 2 feet *Tellina baltica* sand, Saxon and Roman coins?; 3 feet peat, 3 feet clay, above fresh water, below Scrobicularia; 1½ feet peat; rooted trees; boulder clay from half ebb to the lowest tide level.

this period has been proved to within 8 millimeters[1]. The position of Roman constructions outside the dunes renders it highly improbable that any oscillation has occurred along the coast from the Scheldt to Vlieland within the last two thousand years[2], notwithstanding the fact that coins which date from 270 A.D. have been found in the peat beneath marine sand between Dunkirk and Calais, in what was once the bay of the lower Aa[3]. J. Girard does not believe that a continental oscillation is to be inferred from this locality; in his opinion the alternation can be explained without having recourse to such an hypothesis[4].

The detailed investigations of Ormerod at Teignmouth, Devon, show that no displacement of the strand-line has occurred there for a very long period. Boyd Dawkins adds that the existing position of the Roman harbours indicates with equal certainty the unchanged position of the strand on the south coast of England[5].

Forchhammer mentions a rampart on the island of Romö, surrounded by a foss, and separated from the sea by a flat marshy meadow. The position is such as to preclude the possibility of any change of level having occurred since these intrenchments were constructed, that is, since the time of the Vikings. Nevertheless a peat bog lies between Romö and the mainland, about ten feet below the surface of the sea[6].

(*b*) If the land had subsided slowly and uniformly, much in the way it is customary to suppose Sweden is rising, then the advancing waves would have destroyed the peat, and we should not meet with trees still rooted in the soil. Forchhammer has given emphasis to this important consideration, and although he is of opinion that a subsidence of the land about the North sea actually took place in prehistoric times, yet for the reason just given he believes that the event was in all probability sudden, and that it certainly came to an end long ago.

(*c*) In those places where series of alternating peat and marine beds can

[1] v. Bakhuyzen, Verhandlungen der VII. allgemeinen Conferenz der europäischen Gradmessung zu Rom, 1883, 4to, Berlin, 1884, p. 55.

[2] Bakhuyzen et Pleyte, Lettre à M. Faye; Compt. rend., Paris, 1883, XCVII, p. 728.

[3] Here there lie: 0·2 meter marsh land, 0·6 meter brackish clay with *Rissoa ulvae*; 1·65 meters marine sand, bivalves in natural vertical position, at the base rolled Roman remains; 1–3 meters peat with Gallo-Roman remains, sometimes treasures of Roman age; coins up to 270 A.D., substratum of blue clay. Debray, Tourbières du littoral flamand et du département de la Somme, Bull. Soc. géol. de Fr., 1873, 3e sér., II, pp. 46–49, and Railway de Bourbourg à Dunkerque, Ann. Soc. géol. du Nord, 1876, III, p. 88; in particular Gosselet et Rigaux, Mouvement du sol de la Flandre depuis les temps géologiques, op. cit., 1878, V, pp. 218–226.

[4] J. Girard, L'Affaissement du sol des Pays-Bas; Bull. Soc. géogr. Paris, 1879, 6e sér., XVIII, pp. 374–381.

[5] G. Wareing Ormerod, Old Sea-Beaches at Teignmouth, Devon; Quart. Journ. Geol. Soc., 1886, XLII, pp. 98–100; Boyd Dawkins, tom. cit., p. 100.

[6] Forchhammer, Om den forandrede Vandhöide ved de danske Kyster; Nord. Univ. Tidsskrift, Kjöbenh., 1856, 2. Aarg., p. 17.

be traced inland, the several beds of peat are found to unite together into a single seam of greater thickness; a fact absolutely inconsistent with a submergence due to a general continental oscillation. The marsh of Dol, in the département d'Ille-et-Vilaine, north of Rennes, has been expressly described by Durocher and Chèvremont as a proof of such oscillation. According to Sirodot the land beneath the marsh is formed of alternating beds of peat and marine sand; the peat beds maintain a constant thickness as they proceed towards the sea, the marine beds increase in thickness in the same direction, but towards the interior thin out altogether, so that the peat beds come into contact and form a single seam from five to seven meters in thickness, which, keeping the same level, extends all round the margin of the marsh. Sirodot is of opinion that continental oscillations will not explain the facts, and that the several layers of marine sand correspond to so many temporary openings in a bar which once connected the islands of Normandy with the mainland[1].

6. *Bars and peat bogs of the Baltic coast.* All the preceding observations favour the conclusion that a general displacement of the strand-line, such as might result from a continental oscillation, has not affected these coasts for a very long period, perhaps not since the Neolithic age; and further, that the submergence of forests and peat bogs must be ascribed to local irruptions of the sea during storms. A continental oscillation could scarcely have left the works constructed by the Romans or the Vikings in their existing position; local irruptions, on the other

[1] J. Durocher, Observations sur les forêts sous-marines de la France occidentale et sur les changements de niveau du littoral, Compt. rend., Paris, 1856, XLIII, pp. 1071–1074; A. Chèvremont, Les Mouvements du sol sur les côtes occidentales de la France et particulièrement dans le Golfe Normanno-Breton, 8vo, Paris, 1882, pp. 225–436, maps; Sirodot, Age du gisement du Mont-Dol, constitution et mode de formation de la plaine basse dite Marais de Dol, Compt. rend., 1878, LXXXVII, pp. 267–269. The shell beds described by Sirodot and assigned to the Diluvial period, occurring at a height of 14 meters, are much older than the phenomena discussed here. Peacock relates that on the adjacent island of Jersey a wood is said to have subsided as late as the fourteenth or fifteenth century, and its remains may be seen in the bay of Saint-Ouen. Until quite lately taxes were paid for privileges connected with this wood; Geol. Mag., 1876, 2nd Ser., III, p. 130. From phenomena on the Somme a recent elevation of the land to the extent of 220 meters has been deduced. The facts according to Mercey are as follows:—The peat is 7–8 meters thick; above it rise little bosses about 4 meters high, the *croupes de la Somme*. Their nucleus is formed by a knoll-like mass of calcareous tuff with *Neritina fluviatilis*, *Pisidium amnicum*, &c., and fragments of Gallic pottery. On the irregular surface lies a covering of calcareous sand with numerous land and fresh-water mollusca, Roman pottery, and then *Cardium edule*, *Mytilus edulis*, and rarely *Donax trunculus* and *Scrobicularia piperata*. These reach a height of 19 to 20 meters, and are covered by alluvium containing Unio. N. de Mercey, Note sur les croupes de la Somme à Ailly-sur-Somme, &c.; Bull. Soc. géol. de Fr., 1877, 3e sér., V, pp. 337–348. It has not even been definitely established whether these shells are kitchen remains; at any rate they lie with relics of human industry in a *fresh-water bed*, and if only for this reason lend no support to the theory of negative movement.

hand, might conceivably leave unaffected the intervening tracts of land. The subsidences were rapid, otherwise the trees would have been uprooted; and rapid subsidence is what would happen in association with local inbreaks, but not with continental oscillations. Wherever the facts can be ascertained the peat beds which alternate with marine sand unite together as they proceed towards the interior to form a single seam; this is just what would happen if the sea were driven at repeated intervals over a quaking bog, but, generally speaking, oscillations could never bring about this result.

These supposed indications of continental subsidence encroach on the domain of the alleged Scandinavian uprise; we must now therefore follow them towards the east.

Nilsson and Lyell, starting from erroneous assumptions, believed that Sweden is now experiencing a tilting movement about an axis situated in the neighbourhood of Södertelje[1]. Forchhammer was of opinion that the great Scandinavian region in which the elevatory phenomenon occurs is bounded by a line drawn from the middle of the Nissumfjord to within half a mile south of Nyborg, and thence further to the south-east. But he believed that this line should not be regarded as the axis of a tilting movement, because no general subsidence can at present be discerned to the south and west of it, whereas the uplift on the north is still in progress. Indeed in that region where the two movements appear to meet, as in the south of Sweden for instance, the subsidence can be shown to be anterior to the elevation.

Now that we again enter the region of the Baltic we may recall the fact that this sea is also visited from time to time by violent storms, which leave their signs upon the coast. The storm of November 12–14, 1872, already mentioned, was the most violent that had occurred since the year 1694, so far as we can judge from the marks left on the Blue Tower at Lübeck. Baensch and Colding have each written a monograph upon it, and from these we obtain the following general account[2]:—

[1] E. Erdmann has supported this view. Nilsson's statement as to subsidence, indicated by a decrease of the land before the 'Staf-Sten' near Trelleborg in Scania, rests on a printer's error in Linné's Skänska Resa (Geol. Fören. Stockh. Förh., 1874, I, pp. 103, 104), and Lyell's observations on Södertelje have been disputed by Hisinger in 1840, Axel Erdmann in 1868, and finally by O. Torell in his Traces plus anciennes de l'homme, pp. 9–14.

[2] Baensch, Die Sturmfluth an den Ostsee-Küsten des preussischen Staates vom 12. bis 13. November 1872, 4to, Berlin, 1875 (from the Zeitschr. f. Bauwesen, Jahrg. XXV), 33 pp. and pl.; A. Colding, Nogle Undersögelse over Stormen over Nord- og Mellem-Europa af 12–14. Nov., 1872, og over d. derved fremkaldte Vandflod in Ostersöen, Vidensk. Selsk. Skr. Kjöbenhavn, 1881, 6 Række., I, Bd. IV, pp. 245–304, pl. Also G. von Boguslawski, Zeitschr. f. Meteorol., redig. von Jelinek und Hann, 1872, VII, pp. 408–410, and note p. 396. For similar phenomena see Der Durchbruch der Insel Hiddensee, Peterm. Mitth., 1868, pp. 377, 378.

On November 12 an area of high barometric pressure was situated over the north of Sweden, in the course of the next few days it moved gradually away into north Russia; correspondingly there was a low-pressure centre at Vienna on November 12 at midnight; on the 13th it reached Eger, on the same day at midnight, Amsterdam. The maximum thus moved towards the south-east, and the minimum to the north-west. With this displacement of the minimum the path of the winds towards the centre was deflected, and the gale, which at first blew from the north-east, now came from the east; but these directions correspond so closely with the lie of the Baltic that the winds were able to pile up enormous masses of water, which they rolled before them from the northernmost parts of this sea, first to the south, then to the south-west, and finally to the west, and so right up to the exits.

On the 13th, at two o'clock in the morning, the storm reached Colbergermünde, driving a mighty wave before it, the summit of which by six o'clock in the morning had already reached Fehmarn. Here the waters mounted up, held in between Fehmarn and Laaland. Behind them, between Rügenwalde and Swinemünde the surface of the sea was concave, so great was the pressure of the storm; with a rapid rise the sea rushed through the belt of Fehmarn, and at 3.40 p.m. attained a height of +3·17 meters above mean tide at Ellerbeck, near Kiel; it flung its waters over the top of the lighthouse, fifty feet in height, at the mouth of the Schlei, and at about 5.30 p.m. rose to +3·5 meters at Arösund at the entrance of the Little Belt; long before this the force of the wind had passed its maximum, and the great wave was carried onwards by its own momentum. Finally the water was discharged through the Belt.

While this was happening on the coast of Germany, something similar occurred in the Sound, though, as it seems, a little earlier. On November 12, at six o'clock in the afternoon, the level in the gulf of Finland stood at −0·6 meter, between Stockholm and Pillau at zero, at Bornholm it was already +0·95 meter, and at Ystad +1·27 meters. At Falsterbo it was considerably lower, but rose towards the Sound, as well as towards Nyord at the entrance to the Great Belt; at this time indeed the storm from the north-east which drove the waters of the Cattegat towards the exits of the Baltic was still at its height. The veering of the storm from north-east to east brought more water out of the Baltic, but relieved the mouth of the Sound, so that in the latter the highest level was passed on November 13 between midday and two o'clock in the afternoon.

This tremendous disturbance of the Baltic left its traces on the land. Shores of clay were torn up, the cliffs driven inland, beaches broadened; the dunes were overwhelmed, the land behind them inundated, and then as the sea fell the imprisoned water flowed back and breached the dunes. Along the western part of the German coast there is not much dune formation;

a low bar or spit, thrown up by the waves, usually accompanies the shore. The effect of the storm on these depended on the angle at which they encountered the waves. Sometimes their height was augmented, sometimes they were destroyed for miles in length, and at various places on the German side of the Little Belt, where bars exist, they were driven inland with remarkable regularity for a distance of about ten meters [1].

In any case it is now obvious that in straits where a forced rise of the sea may occur, extreme caution is necessary in studying the ancient strand-lines, and it is precisely in these regions that we may expect to find spits and bars abandoned by the sea, remaining, like moraines, to indicate the maximum effect of former storms.

But the evidence for a subsidence of the ground and its subsequent elevation rests chiefly on the existence of derelict bars and beaches superposed on peat bogs.

Forchhammer adduces as signs of elevation remnants of such deserted bars along the whole west coast of Denmark as far down as the mouth of the Nissumfiord in the south, along the east coast down to half a mile south of Nyborg in Funen, along the whole of the east coast of Zealand, and parts of the east coast of Moën.

The coast of Scania has been studied by Nilsson, and later by E. Erdmann and Nathorst; at several places in the neighbourhood of Helsingborg a bar occurs resting on a compressed peat bog; the peat contains flint implements, and is continued inland beneath the bar. Nathorst describes a part of this bar situated to the north of Malmö; it lies 3,000 feet away from the margin of the sea, but the intervening shore is certainly very flat [2].

The Sound is similarly bordered on each side by deserted beaches.

The beach near Trelleborg bears the name of *Gäravalle*; the peat is found there at two feet above the sea, and in some places, according to E. Erdmann, as much as six feet. The beach attains a thickness of ten feet. The fact that the beach is superposed upon the peat appears to me to show that it has been driven inland, and Erdmann's sketches accord well with this view. The existing negative movement may, perhaps, produce a perceptible effect here; indications of a preceding positive movement are absent.

The remarkable sections in the harbour of Ystad have been described

[1] 'The sea has carried out this work with great regularity, and when we contemplate this remarkable growth, often extending for miles, it becomes intelligible that popular belief, unable to explain such an effect, should ascribe the formation of the Holy Dam near Dobberan to a saint who erected it at the command of the monks in a single night for the protection of the cloister.' Baensch, mem. cit., p. 26.

[2] E. Erdmann, Bidrag till Frågan om Skånes Nivåförändringar, Geol. Fören. Stockh. Förh., 1874, I, pp. 93–104, pl.; A. G. Nathorst, Om Skånes Nivåförändringar, tom. cit., p. 281–294.

by Bruzelius. Resting on a mass of morainic débris, the surface of which lies 11 feet below the sea, are peat and a forest growth still rooted in place, with associated remains of the Bronze age; the forest extends from the harbour out to sea. The whole is covered up by a recent marine deposit. At the south-west point of Sweden, three-quarters of a mile outside Falsterbo-Ref, there occurs, according to Nilsson, a bed of peat 10 to 12 feet thick, with its surface 14 feet below the sea-level. South of Bornholm a pine forest occurs 30 feet below the sea. The occurrence of alternate beds of peat and marine sand at Gothland has been described by Lindström [1].

The existing position of deserted bars and beaches resting on peat beds, such as we have just discussed, has no doubt been to a great extent determined by storms, especially in the case of those bordering the Sound. The submerged forests, in the light of the knowledge we have acquired in the North sea, show that certain parts of the Baltic were impounded in a prehistoric period by natural dams. As to the extent of these embankments, destroyed no doubt for the most part during the Bronze age, I will not venture an opinion. They afford no evidence of a continental oscillation, and can only be regarded as terms in a great series of littoral phenomena such as are presented on the shores of the North sea.

Let us now briefly pass in review the results of this chapter; they are as follows:—

Through the English channel the flood tide pours into the south part of the North sea: on the north coast of the continent, from Calais to the Horn of Skagen, a long line of bars, swinging in regular gentle curves, has been thrown up by the united efforts of the wind and sea. Certain fixed points of attachment were afforded them at the outset by the ancient moraine land of Scandinavian origin; the island of Texel is a good example of such a point, and the Kurische Nehrung, as Berendt has shown, presents two such points of attachment, one at its southern end, and the other towards the middle, near Rossitten [2]. Under the shelter of these bars the whole of the vast alluvial plain of the Netherlands, save for some parts which consist of Scandinavian boulder clay, was built up slowly and in the course of ages, without any apparent signs of elevation or subsidence.

[1] N. G. Bruzelius, Fynden i Ystads Hamn, Samlingar till Skånes Historia, 8vo, Lund, 1871. Sharing Nathorst's doubts I have disregarded the asserted presence of a much more recent artificial product below the surface; G. Lindström, Om postglaciala Sänkningar af Gotland, op. cit., 1886, VIII, pp. 251–281. De Geer's observations on a subsidence include no remains of human civilization, and therefore do not concern us; G. de Geer, Om en postglacial Landsänkning i södra och mellersta Sveriga, Sver geol. Unders., 1882, ser. C, No. 52, 16 pp. (also Geol. Fören. Stockh. Förh., VI).

[2] G. Berendt, Geologie des Kurischen Haffes und seiner Umgebung, 4to, Königsberg, 1869, map.

Staring has shown, and after him Winkler, that in Groningen, the Drenthe, and Friesland as far as the Zuyder Zee, Scandinavian moraine land occurs, but that further on, in Over-Yssel, Geldern, and the remainder of the plain, the deposits are alluvial, formed of the sediments of the Rhine, the Meuse, with others of mixed origin[1].

Smaller bars existed as far as Normandy, the south of the Baltic, and along many parts of the English coast. When fresh water accumulated behind them peat bogs were formed, often as 'hammocks,' or quaking bogs which floated on the surface of the bog water.

Violent storms have from time to time destroyed these structures, or hurled the waves over the dunes on to the bogs. The Cimbric flood perhaps corresponds to one of these episodes, and similarly destructive storms have continued down to our own times. In this way the great irruptions into the Netherlands were brought about, and on the Dollart, and so too the bar was torn to pieces, which once extended from Eiderstedt, through Amerane, Sylt, and Romö, towards Fanö, and Blaavands Huk in Jutland, and cut off the existing 'Wattenmeer' of Holstein. At the present day in place of the ancient lagoons we meet only with peat bogs, which have sunk through the yielding of their base, or have been overwhelmed when in the quaking stage; and in front of the dunes lie the peat bogs which the weight of the advancing sand has pressed down beneath the level of the sea.

None of these examples, however, show any signs of oscillation of the earth's crust during the long period occupied in their formation; they imply, on the contrary, a prolonged state of repose.

The North sea receives the overflow of the Baltic, an inland lake, continually endeavouring towards an equilibrium with the Ocean, which it never attains; as is shown by its inferior salinity, and the constant flow of its interior currents. Its monthly means fluctuate with the seasons; rainfall, snow, and times of thaw exert a dominant influence on the Finnish and Swedish coasts. The yearly means are likewise variable; for the last few decades they indicate on the whole a sinking level, though the movement is subject to much interruption, and does not seem to have been in progress for more than two or three hundred years; the explanation which is least far fetched is apparently to be found in a change of climate.

From Haparanda to Brittany there is no evidence of elevation or subsidence of the land since the Bronze age. The visible and obvious modifications of the coast have been brought about sometimes by local landslides, at others by local irruptions of the sea into districts protected

[1] T. G. Winkler, Sur l'origine des dunes maritimes des Pays-Bas; Arch. Néerland., Harlem, 1878, XIII, pp. 417-427, map of the different alluvia.

by littoral bars, or again by storms, and finally, as in the Baltic, they are the result of a climatic change.

In the course of my investigation into the oscillations in the Scandinavian region, I was very early led to inquire whether any extension of the movements observed in the Baltic could be recognized on the coasts in the extreme north of Europe, where indeed it should be most obvious, if, as is alleged, the elevation increases towards the north. Norway furnished no information. The sole traces of existing negative movement, and these questionable, occur in the *Solowetzky islands* in the White sea. I am indebted for my knowledge of them to the great kindness of Professor Inostranzeff. He has observed parallel beds of beach pebbles on the little island of Andersky; and is led to suppose that a negative displacement still continues, by the existence of certain streaks or bands at the foot of the sea-wall, which was built in 1799 below the cloister of Solowetsky and close above the sea-level. Probably the White sea is characterized by the same phenomena as the Baltic and Baffin bay, but unfortunately continuous observations which might throw light on this point do not exist.

CHAPTER XI

THE MEDITERRANEAN DURING THE HISTORIC PERIOD

The sea of Azov and the Black sea. Locus of maximum depression in the surface of the Mediterranean. The western Mediterranean. Venice. The Dinaro-Tauric region. The south-east Mediterranean. Conclusion.

At Meissau in lower Austria, on the eastern slope of the Manhart mountains, barnacles may be seen still attached to the wave-worn granite bosses, on which they grew in the sea of the first Mediterranean stage. On the eastern slope of the Kahlenberg, overlooking the city of Vienna, we may pick up on the beach of the second Mediterranean stage pebbles which have been drilled by boring molluscs. High up on the limestone cliffs of Capri may be seen rows of perforations produced by similar shells at a later period. Finally on the existing shore or in its immediate neighbourhood, far below all these relics of the ancient phases of the Mediterranean, lie numerous ruined harbours and other monuments of antiquity, serving to remind us that the successive shores revealed by this series of vestiges belonged to that classic sea which has witnessed some of the most important events in the history of civilization and which indeed has in no small degree contributed to its beneficent advance.

Here more than anywhere else we are afforded an opportunity of investigating the question as to whether changes of sea-level have occurred during the historic period, but here also more than elsewhere caution is necessary, lest we should confound evidence relating to prehistoric times with that of later date.

1. *The sea of Azov and the Black sea.* From the mouth of the Don in the sea of Azov as far as the Pillars of Hercules there extends at the present day a chain of seas, which appear to discharge successively one into the other, and finally to pass in a united outflow through the strait of Gibraltar into the Atlantic Ocean. Such, however, is by no means the case. The sea of Azov overflows into the Black sea, and this, in spite of a contrary undercurrent in the Dardanelles, overflows in turn into the Mediterranean. But the Mediterranean, owing to excessive evaporation, which is not compensated by the insignificant rainfall, loses such a vast quantity of water, especially off the north coast of Africa, south of Crete, that neither the excess from the Black sea nor the supply from tributary rivers is

sufficient to make good the defect. Consequently the heavy Mediterranean water passes out over the bottom of the strait of Gibraltar, while Oceanic water flows in, always striving to establish equilibrium, but never succeeding in the attempt.

We may therefore describe the Black sea together with the sea of Azov as active members of the chain, but the Mediterranean and in particular its eastern half as a passive member. It is the insertion of this passive member that constitutes the most important difference between this and the north European chain of basins, which are exclusively active.

The *sea of Azov* is shallow; its eastern extremity is the estuary of the Don, and in the roads of Taganrog its waters are fresh. In the middle of the sea, F. Göbel found a salinity of 1·188 per cent. (sp. gr. 1·0097), but towards the west the long bar of Arabat cuts off a great lagoon, the *Sivash* or *Putrid* sea, leaving open a channel of communication only seventy-five fathoms broad. The Sivash is intensely salt owing to evaporation; Göbel and Hasshagen found a salinity of 17·374 per cent. (sp. gr. 1·13988), and of 15·197 per cent. (sp. gr. 1·13795); this is a good example of a sea which has become passive by isolation [1].

Levels taken by Guillemin many years ago, from the Black sea to the sea of Azov, gave for the latter +1·45 meters at Ak-Manaï, but I can find no detailed confirmation of these measurements [2].

The Russian government appointed a scientific commission to investigate the sea of Azov and to ascertain whether its asserted decrease in depth was actually taking place. The report drawn up by Baer in 1863 shows that since the time of Polybius, and of Strabo, who wrote a very exact description of the region, no change in the water-level at all worthy of mention has occurred. The ruins of Tanis, a commercial city mentioned by Strabo (xi. 2), have been discovered on the shores of a deserted arm of the Don; opposite Taganrog, outside the delta, the little low island of Tsherepacha, probably the island of Alopekeia mentioned by Strabo, may still be seen, and what is most significant Strabo even describes the spit of Arabat, and the Sivash, which he speaks of as a marsh separated from the sea on the west; but the opening at the northern end of the spit appears to have been much broader at that time. At the present day the island of Tsherepacha is still so low that it is submerged during high winds [3].

[1] F. Göbel, Resultate der Zerlegung des Wassers vom Schwarzen, Asow'schen, und Kaspischen Meere, Poggendorf's Ann. Phys. Chem., Ergänzungsband I, 1842, pp. 187, 188: A. Göbel, Ueber die in dem Bestande einiger Salzseen der Krym vor sich gehenden Aenderungen, Bull. Acad. Imp. Sci. St.-Pétersb., 1863, V, pp. 290-299 (here also Hasshagen's results).

[2] J. Guillemin, Niveaux comparés de la Mer d'Azof et de la Mer Noire; Bull. Soc. geogr. Paris, 1865, 5e sér., IX, pp. 97, 98.

[3] As to the assertion that the sea of Azov is becoming shallower, see the report of the Commission appointed by the Academy of Sciences of St. Petersburg, written by Baer;

Sarmatian folds, running from the northern border of the Caucasus to the northern border of the Crimean mountains (I, p. 474), separate the sea of Azov from the Black sea.

The *Black sea* resembles the Baltic in many respects. The salinity of the water is only a little higher than that of the sea of Azov and its level is subject to seasonal oscillations like those of the Baltic. The oscillations have been studied by E. von Maydell, and Brückner has shown that they depend on variations in the river supply. The chief tributaries of the Black sea, the Danube, Dniepr, and Don attain their highest level in the months of April and May. The observing stations which are subject to the direct influence of the rivers, those for instance at Otshakow, Odessa, Kerch, Genitshesk, and the mouth of the Dniestr, show the highest sea-level in May, that is a little later than the rivers, while at the stations lying further away from the rivers, namely Sebastopol, Yalta, and Poti, the highest level occurs still later, i.e. in June. Thus in May and June the sea stands +0·1 to +0·15 meter above mean level; it then sinks as winter approaches, remains at a height of −0·08 to −0·11 meter from September to March, and then rises again to the maximum. Thus the whole volume of water in the Black sea fluctuates from season to season [1].

In complete accordance with these results are Wrangell's observations on the density made in the autumn of 1873. The highest density observed was off the west and south coasts of the Crimea, which are remote from the rivers; it ranged from 1·0139 to 1·0145, with a maximum corresponding to 1·9 per cent. near the south point of the Crimea; and off the coast of the Caucasus, also remote from the great rivers, the density varied from 1·014 to 1·0143, with a maximum salinity of 1·87. Near the rivers, on the other hand, the salinity decreases; thus in the liman of the Dniepr it sinks to 0·6 per cent. (sp. gr. 1·0045), in the bay of Taganrog it is 0·73 per cent. (sp. gr. 1·0056) [2].

Bull. Acad. Imp. Sci. St.-Pétersb., 1863, V, pp. 72–105, map; and G. von Helmersen, op. cit., 1867, XI, pp. 555–584. A full abstract of the first of these memoirs is contained in H. Ritter, Die Verflachung des Asow'schen Meeres; Zeitschr. f. allg. Erdk., Berlin, 1862, XII, pp. 305–326. The very remarkable *Kossi*, i.e. parallel tongues of land with hook-shaped appendages on the inner side, are characteristic of the sea of Azov; Helmersen has described in detail that of Berdänsk. Here doubtless lies the explanation of those hook-shaped bays which Gilbert has figured in the basin of the ancient lake Bonneville, U.S. Geol. Surv., 5th Annual Report, 1883 to 1884, pl. XII; Helmersen's sketch was taken at high tide.

[1] E. Brückner, Die Schwankungen des Wasserstandes im Schwarzen Meere und ihre Ursachen; Meteorol. Zeitschr., 1886, III, pp. 297–309. On the exchange of water in the Bosphorus, see Makarof, Ann. d. Hydrogr., 1886, pp. 532–535.

[2] F. Wrangell, Einige Dichten- und Temperaturbestimmungen im Schwarzen und Asow'schen Meere, in A. Kaspárek, Studien über die physikalischen Verhältnisse des Schwarzen und Asow'schen Meeres; Mitth. aus d. Gebiete des Seewesens, Pola, 1886, XIV, pp. 327–332, map.

Thus oscillations of the same character as in the Baltic occur in the Black sea, but their sum does not give a negative value. Strabo, who, as we have seen, described the spit of Arabat in the sea of Azov, has also given an exact account of the existing spit of Perekop, which he speaks of as 'The Course of Achilles' (vii. 3. 41), and a study of this has led the Commission of the Russian Academy to the inference that no important change has affected the level of the Black sea for 2,000 years.

Indications nevertheless exist of a movement which must have occurred near the beginning of historic times, certainly after the glacial period. The evidence is as follows:—

It has already been pointed out (I, p. 344) that the region now occupied by the Aegean sea was previously a land-surface covered by fresh-water lakes; it suffered collapse, and the sea of the fourth Mediterranean stage advanced across Milos, Rhodes, and the south part of the island of Kos. Still later the subsidence was renewed and continued as far as the Black sea, and then for the first time the Mediterranean entered the region of the Pontus and the sea of Azov. In the Dardanelles, however, Mediterranean shore deposits lie high above the existing strand. As early as 1857, Spratt recorded recent marine beds with oysters north of Meitos, as well as on the opposite coast of the straits at a height of +40 feet; and he thought the sea-level must have stood about fifteen to twenty feet higher. Calvert and Neumayr have confirmed Spratt's observations, and from their account it would appear that a flint implement has been found in the deposits [1]. Some traces of these recent sediments, which are never raised far above the existing strand and always retain their horizontality, are found even within the Pontic basin; their fauna, which is that of the existing Mediterranean, shows that the Pontus at this time, when its waters stood at a higher level, was not as fresh as at present, but nearly as salt as the Ocean. Abich has described these sediments as they occur in the straits of Kerch and in the peninsula of Taman, and Tchihatchef has recognized them south of Samsun, near the north coast of Asia Minor [2]. Thus it appears that at the time when the Pontic region was in free communication with the Mediterranean the level of the water was somewhat higher than at present. The sea

[1] T. Spratt, On the Geology of Varna, &c., Quart. Journ. Geol. Soc., 1857, XIII, p. 81; Frank Calvert und M. Neumayr, Die jungen Ablagerungen am Hellespont, Denkschr. k. Akad. Wiss. Wien, 1880, XL, p. 366 et seq.; also C. Peters, Grundlinien zur Geographie und Geologie der Dobrudscha, op. cit., 1867, XXVII, p. 198.

[2] H. Abich, Études sur les presqu'îles de Kertsch et de Taman, Bull. Soc. géol. de Fr., 1864, 2e sér., XXI, p. 270 et seq.; Beyer's observations, tom. cit., p. 279; P. de Tchihatchef, Dépôts tertiaires d'une partie de la Cilicie Trachée, etc., Bull. Soc. géol. de Fr., 1854, 2e sér., XI, p. 392. Tchihatchef gives 80–90 feet as the height of the shell beds, but since they lie half a league away from the sea, and the height is merely an estimate, which must have been very difficult to make from a distance, I have not attached much value to these figures.

entered with its full salinity; its shores were formed, then as now, to a great extent of loess. Then freshening set in, accompanied by negative movement. The sea of Azov enlarged itself by destruction of its shores; and finally the Sivash was shut off[1].

2. *Locus of maximum depression in the surface of the Mediterranean.* Wherever exact measurements have enabled us to compare the Mediterranean with the Atlantic its surface has been found to lie below that of the Ocean. The following figures are taken from the reports of the International Geodesic Association and the communications made to it by various European governments:—

	Meters.
Swinemünde—Trieste . . . . =	−0·499
Swinemünde—Marseilles . . . =	−0·664
Calais—Marseilles . . . . . =	−0·753
Brest—Marseilles . . . . . =	−1·022
La Rochelle—Marseilles . . . =	−0·400
Bayonne—Marseilles . . . . =	−0·856
Santander—Alicante . . . . =	−0·663[2].

These negative values show that the Mediterranean is a passive region, and Forchhammer's chemical analyses lead to the same result. This investigator found that the density in the Atlantic Ocean increased off the west coast of Africa under the influence of the Sahara; and that Atlantic water entering the Mediterranean at Gibraltar has a salinity of 3·63 per cent. But in long. 4° 2′ W. the salinity has already risen to 3·7; between the Balearic isles and Spain it is 3·8 and 3·83, at Malta 3·85; off the coast of Greece, no doubt under the influence of the Bosphorus, it is slightly less, falling to 3·8; the maximum which Forchhammer records was found in samples taken between Crete and the coast of Africa; it amounts to 3·93 per cent. The subsequent work of Carpenter confirms these results. He found a density of 1·0271 for the inflowing water at Gibraltar taken at the surface, and of 1·0293 (salinity 3·91 per cent.) for the outflowing water in the undercurrent at a depth of 250 fathoms; at the surface the density off Sicily is 1·028 to 1·0284, between Malta and Crete 1·0284 to 1·0288, not far from the gulf of Solum or Milhr (Mellah) on the eastern boundary of Barca 1·0293 (in 1,650 fathoms 1·0294), and still nearer the coast of Africa 1·0294 (in 365 fathoms 1·0302). The greatest density in the Mediterranean thus occurs between the coast of Africa and Crete, where evaporation reaches a maximum and the supply of fresh water falls to a minimum[3].

[1] C. Peters, Die Donau und ihr Gebiet, 8vo, Leipzig, 1876, pp. 333, 334.

[2] Verhandlungen der permanenten Commission der Europäischen Gradmessung in Hamburg, 1878, 4to, Berlin, 1879, pp. 62–66; and Verh. der VII. Conferenz, Berlin, 1884, p. 270 et seq. The value −0·664 m. for Swinemünde—Marseilles was obtained by levelling through Switzerland; through Amsterdam and Ostend −0·658 was obtained.

[3] G. Forchhammer, On the Composition of Sea-water in different parts of the Ocean,

Hemmed in as the Mediterranean is by surrounding land, its level must depend on the ratio between evaporation and supply and thus will necessarily differ from that of the Ocean; though certainly not to the extent assumed by Bianconi when he attempted some years ago to explain the horizontality of the relict strand-lines[1]. Again, we may fairly conclude that *the level of the Mediterranean is lowest between Crete and the coast of Africa, since this is the locus of maximum density.* It is lower here than even at Alicante, Marseilles, or Triest, where its height has been ascertained by direct measurements. These measurements have given negative values throughout; but it is readily intelligible that in the northern part of the Adriatic, which is subject to the influence of the Po, the negative value should be slightly less marked, and in accordance with this Luksch and Wolf have found a somewhat lower density on the Italian than on the Austrian side of this region[2].

Carpenter's observations show further that water with a uniform temperature of 13° to 14° C. and with no appreciable signs of circulation, occupies the western Mediterranean from a depth of about 100 fathoms downwards, while the temperature of the Ocean at the same depth is much lower; in the eastern Mediterranean, on the other hand, the heat of the sun certainly penetrates below 100 fathoms, but in this basin also stagnant water is reached before a depth of 200 fathoms. This mass of deep water appears to be undisturbed by currents and scarcely any interchange takes place with the overlying layers. The temperature of the upper water reaches 26·5° C. in the hottest regions, or even more, and the maximum lies a little below the surface, the surface itself being cooled by rapid evaporation.

Let us return for a while to that part of the sea situated south of Crete. Although the negative values quoted above for the mean level on the south coasts of France and Spain are not altogether negligible and even reach −1·022 meters between Brest and Marseilles, yet the density in these western parts of the Mediterranean is only a little greater than that of the Ocean, and it is therefore probable that the fall of level is much more considerable south of Cyprus and on the borders of Africa. This may be

Phil. Trans. London, 1865, CLV, pp. 203–262; W. B. Carpenter and J. Gwyn Jeffreys, Report on Deep-Sea Researches carried on during the Months of July, August, and September, 1870, in H.M. Surv. Ship *Porcupine*, Proc. Roy. Soc., 1871, XIX, pp. 146–221; and Carpenter, Report on Scientific Researches carried on during the Months August, September, and October, 1871, in H.M. Surv. Ship *Shearwater*, op. cit., 1872, XX, pp. 535-644. T. Fischer estimates the depth of water which yearly evaporates over the Mediterranean at 3 meters at least; Peterm. Mitth., 1885, XXXI, p. 415.

[1] J. J. Bianconi, Sur l'ancien exhaussement du bassin de la Méditerranée; Bull. Soc. géol. de Fr., 1865–1866, 2e sér., XXIII, pp. 72–80.

[2] J. Luksch and J. Wolf in F. Attlmayr, Handbuch d. Oceanographie, 8vo, Vienna, 1883, I, p. 360.

inferred from the greater density. The density of the Atlantic water flowing in through the strait of Gibraltar is 1·0271. In the gulf of Milhr it is 1·0293 at the surface, and 1·0294 at a depth of 1,650 fathoms. We will take 1,650 fathoms as the greatest depth and 1·02935 as the mean density at Milhr. A column of water 1,690 fathoms high in the gulf of Milhr would require a column of Atlantic water 6·6 meters higher to balance it. But if we reckon from the maximum density, 1·0302, then we find that *a column of* 1,000 *meters of Mediterranean water at this density corresponds to a column of* 1,003 *meters of Atlantic water.*

It is true we have no precise knowledge either of the form or the depth of the wide funnel which forms the surface of the Mediterranean in this region, but we may fairly assume that it is at such loci of maximum depression that climatic changes would produce the most marked effects on the height of the sea-level. Now it is a remarkable fact that the most important movements of the strand-line which have occurred in historic times have been observed precisely in this region on the south-west coast of the island of Crete, and as far as Cerigotto.

In 1852 Leycester published an observation made by Lieutenant Mansell, who had made measurements of a well-marked strand-line at cape Krio, the south-west corner of Crete, and found a height of +37 feet (11·24 meters). In the north-west of the island, opposite Grabusa, and again at cape Spadha, this line had sunk to about +20 feet (6·07 meters), thence proceeding along the north coast towards the east it descended still lower, and was met with in the bay of Sudha at a height of +6 feet (1·8 meter). The case is similar on the south coast, where the line descends towards the east to disappear against the plain of Gortyna[1].

So many different strand-lines and zones of perforations occur on the coast of Italy, dating from various periods, that this account given by Leycester for the first time must be received with great caution.

In the year 1852 Captain Spratt announced that the whole island of Crete was undergoing a tilting movement; the west had already been very much elevated, the middle had not moved, the east was slightly depressed. He stated in particular that at Phalasarna the whole of the ancient harbour works stand on dry land, which would indicate an elevation of 22 feet 6 inches (6·83 meters).

Some years later, in 1865, Spratt repeated his statements in detail. Many of his observations relate only to strand-lines marked on rocks, and of indeterminate age, but I may cite the following: *bay of Suda* (western half of the north coast), minor strand-lines, boring shells in their holes, up to +2·07 or 2·12 meters; *Kisamo* (north-west coast), the ancient mole raised about 5·47 meters: *cape Grabusa* (north-west point), one of the

[1] E. M. Leycester, Some Account of the Volcanic Group of Milo, Anti-Milo, Kimolo, and Polino; Journ. Geogr. Soc., 1852, XXII, p. 227.

three Corycaic islands mentioned by writers of antiquity, now united to the mainland, strand-lines occur up to +6·68 meters; *Phalasarna* (west coast), the whole foundation of the harbour on dry land, strand-lines up to +6 or 7 meters. The strand-lines without any indication of historic date reach a maximum with +7·9 meters between Selino and Lissos, near cape Krio (south-west coast). A strand-line of this kind is also mentioned as occurring at Zakro in the extreme east of the island.

The traces of positive movement are far less marked. The most striking are: *Metala* (middle of the south coast), some tombs hewn in the rock, partly covered by the waves; *cape Sidara* (extreme east), partly submerged buildings; *Spina longa* (north-east, in the gulf of Mirabello), ruins of a Greek town below water, positive movement 1·8 to 2·4 meters or more. In the same locality, however, Issel found indications of negative movement [1].

It will be seen, for reasons to be mentioned later, that the evidence in the case of all these positive traces is very untrustworthy.

Here we are in presence of a problem which can only be solved by investigation on the spot. *The only signs of negative movement which have been observed on monuments of the historic period*, Puzzuoli excepted, *occur around the locus of maximum depression, produced by climatic influence.* The movement indicated by existing observations is, however, so great (about seven meters), that in the absence of further information I can hardly venture to explain it by change of climate alone; fresh measurements and further investigation of the facts are indispensable.

We will now examine some of the most important evidence presented by the shores of the Mediterranean.

3. *The western Mediterranean.* As regards the character of the shore in the gulf of Milhr itself I possess no information. The negative movement, supposed by Hamilton to have occurred at Benghasi on the eastern side of the gulf of Gabes, is explained by Stacey as the result of local subsidence of the limestone plateau; other examples of such subsidence are not rare in this district [2]. Stache calls attention to the fact that the two islands of Kerkennah and Djarba, two little strips of land just rising above the sea, were already known to Herodotus, and consequently no important change can have taken place on the coast of the Syrtis minor

[1] Extract of a letter from Capt. Spratt on Crete; Journ. Geogr. Soc., 1854, XXIV, pp. 238–239. These and the later statements of Spratt are contained, literally translated, and conveniently arranged in V. Raulin, Description physique de l'Île de Crète, 8vo, Bordeaux, 1869, II, pp. 681–691; for Spina longa see Issel, Oscillazioni lente del suolo, p. 279.

[2] G. B. Stacey, On the Geology of Benghasi, Barbary, and an Account of the Subsidences in its Vicinity; Quart. Journ. Geol. Soc., 1867, XXIII, pp. 384–386. Hamilton, Beechey, and Barth had inferred positive displacement. Also Beurmann, Zeitschr. f. allg. Erdk., Neue Folge, 1862, XII, p. 409; and T. Fischer, Küstenveränderung im Mittelmeergebiete, Zeitschr. Ges. f. Erdk., Berlin, 1878, XIII, p. 156.

since the time of the great historian[1]. Partsch and Rolland agree in showing that no movement has occurred during historic times at Tunis; this is proved, in particular, by the character of the lagoon[2]. Recent marine deposits rest against the coast of Algiers; thus Bleicher has described the traces of an ancient sea which occur on the coast of Oran up to a height of +150 meters, but indications of the strand become increasingly clear as we approach the level of +40 to 20 meters. At a height of +7 or 8 meters fairly regular bands of shelly sandstone are met with; the shells are all of living species; but there is no evidence, so far as I am aware, of a change during historic times[3].

The case is the same at *Gibraltar*; Smith and Maw observed a mass of stratified sand on the east side of the Rock in the bay of Catalan extending to a height of 700 feet (210 meters). Smith found *Patella ferruginea* in it. Strand-lines have been observed on the slopes at various heights, but no evidence has been discovered of movement in historic times[4].

The fact that the town of *Aigues-Mortes* (*Aquae mortuae*), west of the delta of the Rhone, where Louis the Pious embarked in A. D. 1248 and 1270 on his crusades against the Infidel, now stands five kilometers from the sea, has given rise to the notion that great changes must have occurred in this locality at a very recent date. An important fact, however, has been overlooked; the king certainly embarked from Aigues-Mortes, but the town was then as now situated within the region of the lagoons, which Louis caused to be connected with the sea by a canal. Embarkation on the great Genoese and Venetian galleys did not take place in Aigues-

[1] G. Stache, Die projectirte Verbindung des algerisch-tunesischen Chott-Gebietes mit dem Mittelmeere; Mitth. k. k. geogr. Ges. Wien, 1875, XVIII, p. 341. Barth had inferred negative movement; several authors have connected this with the formation of the *Palus Tritonis*.

[2] J. Partsch, Veränderungen des Küstensaumes der Regentschaft Tunis in historischer Zeit, Peterm. Mitth., 1883, XXIX, p. 201 et seq., and 1885, XXXI, p. 154; Rolland, Compt. rend., 1887, CIV, p. 600. T. Fischer, who had expressed an opposite opinion, has since accepted the views of Partsch.

[3] Bleicher, Note sur la géologie d'Oran, Bull. Soc. géol. de Fr., 1875, 3e sér., III, pp. 187–195. Existing species of land shells are also found; some, such as *Alexia Algerica*, occur at a level of 40 meters among the marine shells. These are the concrete beds of Oran observed by Tristram; G. Maw, Geological Notes on a Journey from Algiers to the Sahara, Quart. Journ. Geol. Soc., 1874, XXX, pp. 105 et seq. T. Fischer has collected instructive observations on the erosive action of the waves on the north coast of Africa, but supposes this action to be seconded by a positive displacement of the strand, which decreases towards the east. The facts adduced do not convince me of the necessity of this supposition. Fischer, Küstenstudien aus Nord-Afrika; Peterm. Mitth., 1887, XXXIII, p. 5 et seq.

[4] J. Smith, On the Geology of Gibraltar, Quart. Journ. Geol. Soc., 1846, II, p. 41; G. Maw, On the Evidences of Recent Changes of Level in the Mediterranean Coast Line, Geol. Mag., 1870, VII, p. 552; F. v. Hochstetter, Reise der Novara, 1866, II, p. 4; and Ramsay and Geikie, Geology of Gibraltar, Quart. Journ. Geol. Soc., 1878, XXXIV, pp. 521–525.

Mortes itself, but at a place which still lies, as it did then, on the open shores of the sea, and still retains the name of Grau Louis.

Apart from this, however, the position of Aigues-Mortes and the admirable account of it by Lentheric afford an excellent opportunity for additional observations on the formation of littoral bars.

In our study of the North sea we have already pointed out how the waves falling obliquely on its shelving shores spread out the sand and pile it up before them, forming crescentic dunes or spits miles in length. The wind contributes its action, and when, as is generally the case, the movement is not directed quite at right angles to the coast lateral displacement occurs. If now the mouth of a river is situated say to the east and the displacement is towards the west, then a spit is formed to the west, and this, if it increases till it joins the next fixed point, becomes a littoral bar. Secondary circumstances, however, may somewhat alter the direction of displacement. Then a new spit arises, and in course of time a new bar, separated by a lagoon or marsh from the preceding, which now lies further inland. It is asserted that even a large clump of trees may suffice under certain circumstances to bring about a deviation. The shifting of a river mouth in the delta is much more effective, since a new spit begins to grow from the fresh source of sediment. Nature unaided accomplishes such processes very slowly; when, therefore, we find in the vicinity of a river mouth successive bars visible one behind the other, separated by lagoons, and when these lagoons show no signs of change beyond a gradual silting up, i. e. when the whole series of bars rests on the same horizontal plane, it clearly follows that since the formation of the oldest bar, or that lying furthest inland, no important movement can have affected the level of the strand.

At Aigues-Mortes four 'cordons littoraux' or bars are visible one behind the other; towards the west they unite into a single tongue. Between them lie sheets of water. The town stands between the second and third bar. Grau Louis, where the embarkation of the Crusaders took place, is situated on the outer side of the fourth or outermost bar; and this, the youngest of the series, was already in its existing state six centuries ago. Since the fifteenth century, when the Petit-Rhône was diverted from the neighbourhood of Aigues-Mortes to the east, and made to discharge by a new mouth, another spit has formed, the beginning of a new bar, the Terre-Neuve, and Martins calculates that this, if it continues to grow at its present rate without interruption by storms, will reach the tongue of land directed towards Montpellier, east of Aigues-Mortes, and so form a fifth bar in the course of the next eighteen centuries.

The four bars of Aigues-Mortes rest on such a level base that in 1810, at high tide, the river Rhone entered between all four bars, overflowed the depressions, and washed against the walls of Aigues-Mortes, so that the

gates of the town had to be closed, and large vessels were able to reach the town from the Rhone [1].

The great extension and uniform character of the bars to the west of the mouth of the Rhone bear witness to a long-continued stability in the height of the strand-line. This has been clearly shown by Martins. Only very trifling, perfectly regular and compensatory oscillations are compatible with this state of things, but even of such oscillations we have here no signs.

In the south and east of the delta the growth of the land does not proceed so regularly; in one place the land advances into the sea, in another the sea gains upon the land, tearing away the greater part of the material laid down by the river. Thus it happens that two redoubts erected in the time of Louis XIV now stand out to sea at some distance from the shore.

The stability of the spits and bars of western Italy, the position of the Roman roads upon them, the ancient drain under the rock of Cosa still serving its original purpose, as well as the phenomena at Puzzuoli, have already been discussed.

The whole of the western Mediterranean has been searched in vain for evidence of movement of the strand-line during historic times; on the other hand certain facts, such as the successive bars of Aigues-Mortes, definitely indicate a long-continued stability.

4. *Venice.* The prominent part taken by Manfredi and Frisi in the discussion of movements of the strand-line calls for some reference to the phenomena observed at Venice.

The mouth of the Po is a very instructive region, and has been very closely observed. Accounts of changes in the strand-line date back from the sixteenth century. At the close of the eighteenth century Zendini definitely asserted that the sea-level was rising at Venice; more recently Luciani, Issel, and Koratsch have collected together the various data relating to this question [2]. But in this case also it is necessary, in order not

[1] C. Lentheric, Les Villes mortes du Golfe de Lyon, 8vo, Paris, 1876, in particular pl. xii and pp. 351–383; see Martins, Une Ville oubliée, Aigues-Mortes, son passé, son présent, son avenir, Revue des Deux Mondes, 1874, I, pp. 780–816, also Compt. rend., 1874, LXXVIII, pp. 1748–1750; De Cossigny, Sur la corrélation qui existe entre les oscillations du sol et la configuration des côtes de la mer, Bull. Soc. géol. de Fr., 1875, 3e sér., III, pp. 358–367. The last-named author has maintained the theory that every bar indicates an oscillation; the construction of the fifth line taking place at the present day contradicts this view.

[2] Of the numerous works on this subject I will only mention that of A. Zendrini, Esami di alcuni fatti geologici giudicati da taluno, conducenti a dimostrare l'invariabilità del livello del mare, Mem. R. Ist. Lomb. Veneto, 1843, II, pp. 213–226. The elevation theory was only invoked here in later years; see e. g. Bullo, Sopra la vulcanicità ed il lento abassamento del suolo nella Venezia maritima, 8vo, Padova, 1871; J. Luciani, Movimenti litorali della provincia di Venezia, Boll. Soc. geogr. ital., 1881, XVIII,

to be misled by facts of secondary importance, to consider the phenomena as a whole.

At the present day the Po transports its muddy sediments across the outer border of the Lido and deposits them in the open sea. North of the main part of the delta lies the lagoon region of Venice, and south of it that of Comacchio. In addition to the Po, however, other important rivers, such as the Adige and the Brenta, also discharge themselves close to the Po, and the changes which have affected the lower course of these rivers have not been without influence on the structure of the alluvial land. The Po, at the time of the Romans, discharged a considerable part of its waters to the south-east, in the direction of Ravenna, through the lower course of the Reno, now silted up. Not till much later, since the year 1150 in particular, when the Po had made for itself a new bed at Ficarolo, above Ferrara, and since 1526, when the waters of the Reno above Ferrara were diverted into the Po, did the waters of the latter unite more and more together in the region of its existing mouths, whereas formerly a great part of its sediments was carried into the lagoon of Comacchio. The Adige has often changed its bed, generally moving towards the south. The mouth of the Brenta has been shifted southwards by artificial means.

If now we turn to the charts, and the little generalized maps of Reyer which show the facts very clearly, we shall see that three bars extend side by side from the lagoons of Comacchio across the delta of the Po to the lagoons of Venice, and so flat is all the intervening land, that the Po and the Adige, making use of ancient openings, have been able to shift their lower course transversely across the direction of the bars [1]. Of these bars it is the innermost, i.e. the most westerly, which, as at Aigues-Mortes, must be regarded as the oldest, and since its formation no important displacement of the strand-line can have occurred in the whole of this region. But this bar dates from a period far remote from all historic record.

If notwithstanding this a continuous subsidence of the ground is found to occur at Venice, the cause must be sought in local conditions. Collegno asserted many years ago that it was merely a matter of closer settlement of the alluvium. The subsidence near the mouth of the Sile, which between the eleventh and sixteenth centuries led to the submergence of the flourishing town of Ca di Riva, together with the fertile country surrounding it, must probably be regarded as the result of a local depression of this alluvial land. Not far away is the once important town of Torcello, which in like manner, and possibly owing to a further exten-

pp. 576-585; A. Issel, Le oscillazioni lente del suolo, o bradisismi, 8vo, Genova, 1883, p. 250 et seq.; M. Kovatsch, Die Versandung von Venedig und ihre Ursachen, 8vo, Leipzig, 1882, p. 143.

[1] E. Reyer, Aenderungen der venezianischen und toscanischen Alluvialgebiete in historischer Zeit; Zeitschr. Ges. f. Erdk., Berlin, 1882, XVII, p. 128.

sion of the same subsidence, was gradually converted into marsh-land, and fell into decay. Koratsch states that a fresh-water spring wells up in the crypts of the principal church in this town; this points to a continuance of the movement. The broad basin of the Mille Campi near the present mouth of the Brenta, which has come into existence since the beginning of the seventeenth century, and is now covered by four to six feet of water, must also be regarded as a local subsidence. Luciani believes that although in many cases the cause is local, especially where buildings subside unequally, like the towers of San Giorgio dei Greci and San Stefano, for example, yet a general movement of the strand-line may also be recognized, and he supports this view by observations on the rocky coasts of the northern Adriatic. Reyer believes, like Collegno, that a continuous settlement of the alluvium is in progress, and is inclined to think that the whole mass of alluvium in course of time moves slowly out towards the bottom of the sea.

How mobile the subsoil of the city is has been shown by the artesian wells. After many futile attempts had been made at an earlier period, Degousée succeeded, between the years 1846 and 1849, in sinking numerous deep bore-holes through the saturated land; some of them attained a depth of 120 meters. The water thus reached rose above the level of the streets; it was accompanied by vegetable matter, and frequently by vast volumes of combustible gas, evidently a product of decomposition. In course of time, however, the supply of all these wells has ceased or become very much diminished, and the cause is supposed to lie in subterranean movements of the ground [1].

In some cases the spouting up of the water was accompanied by veritable eruptions; F. von Hauer has described an eruption of this kind which occurred on April 11, 1866, near San Agnese. The boring had reached a depth of about fifty meters, when a jet of mud, sand, and peat shot up more than forty meters high, covering the roofs of the surrounding houses, and converting the streets into streams of mud. The eruption continued with intermittent force for several hours; the ground sank round about, and the neighbouring houses had to be abandoned by their inhabitants [2].

[1] P. Paleocapa, Considerazioni sulla costituzione geologica del bacino di Venezia e sulla probabilità che vi riescano i pozzi artesiani, 8vo, Venezia, 1846; C. A. de Challaye, Sur les puits artésiens à Venise, Bull. Soc. géol. de Fr., 1847, 2e sér., V, pp. 23–26; J. Degousée, Note sur les alluvions formant les lagunes vénitiennes et sur les puits artésiens de la ville de Venise, exécutés par J. Degousée de 1846 à 1849, op. cit., 1850, 2e sér., VII, pp. 481–484; T. A. Catullo, Materie terrose ottenute dalle perforazioni artesiane praticate nel Campo di S. Maria Formosa, Atti R. Ist. Veneto, 1853, ser. 2, IV, p. 167. A general section of the borings after Degousée and Laurent is given by A. Tylor, Formation of Deltas, Geol. Mag., 1872, IX, pl. xi.

[2] F. v. Hauer, Wasserausbruch bei einem artesischen Brunnen in Venedig; Jahrb. k. k. geol. Reichsanst., 1866, XVI, Verhandlungen, p. 65.

The history of Venice recounts many such incidents caused by the peculiar nature of the subsoil. In A. D. 1105 Malamocca was inundated by a great sea-wave, coinciding apparently with an earthquake, and after the catastrophe the town remained under water, so as to be uninhabitable. The bishopric was removed to Murano, as was the monastery of San Cipriano, and in A. D. 1110 the Doge Ordelafo Faliero determined to re-establish the town in a place better protected from the sea[1]. The year 1117 was distinguished by a series of extremely violent earthquakes. Venice and Padua suffered much; the cathedral of Cremona was thrown down and thousands of persons lost their lives[2]; on January 13 of the same year during an earthquake which was very violent at other places, but less felt in Venice, the ground opened and sulphurous water poured forth; by this the church of San Hermagoras was set on fire and burnt down[3].

It would be superfluous to multiply examples, which show to what high degree this alluvial land is saturated with water and combustible gases. Under such circumstances stability of the strand-line is not to be expected; and we have rather reason to marvel that the alluvium has borne the heavy burden of great buildings in comparative repose for so many centuries, and has thereby enabled so brilliant an example of human culture to flourish on this spot.

It cannot be denied, however, that some evidence does exist in favour of a positive movement of the strand-line, which is uniform, though trifling. The most marked change is said to be visible at the foot of the Doges'

[1] It is not quite certain whether an earthquake was the cause; most writers refer to the chronicle of A. Dandolo; he, however, writes (Muratori, Rerum Italicarum Scriptores, XII, p. 260): 'His diebus Mathemaucensis civitas similiter maris proflagrationibus et incendiis devastata, tandem in totum submersa est. Ex quibus angustiis Venetia, cuius fama iam per orbem divulgata erat, in intimum conquassata est. Post haec terraemotus immensis superveniens afflictis afflictionem adiunxit.' Sanuto informs us in his Vitae Ducum Venetorum (Muratori, XXII, p. 485): 'In questo giorno la città di Malamocco, pel mare grande che venne, si sommerse; e fu in Venezia un grandissimo tremuoto, che rovinò assai chiese e case . . . Nel 1110, nell' ottavo anno del ducato di questo Doge, avendosi compassione della chiesa episcopale di Malamocco e della città dal mare sommersa, fu determinato di rifarla più in quà sicura dal mare. . . .'

[2] L. A. Muratori, Annali d'Italia, 4to, Milano, 1744, p. 384.

[3] A. Danduli, Venetorum Ducis, Chronicon Venetorum (Muratori, XII), p. 266: 'XVmo Ducis anno, die 13. Ianuarii Indictione 10ma fuit terraemotus, mitior, alicubi validior, qui aedificia obruit, montes et rupes contrivit; terra etiam aperitur et aquas sulphureas emittit; et ex hoc combusta est Ecclesia Sancti Hermagorae cum adiacentis suis. Manus autem Sancti Ioannis Baptistae divinitus illaesa ab igni permansit.' Sanuto says (op. cit., p. 485): 'Nel 1117, in questi giorni a Venezia fu un grandissimo tremuoto, e venne un' acqua sulfurea, che appiccò fuoco nella chiesa di Sant' Ermagora, e quella abbrucciò. Ma la man destra del glorioso S. Giovanbattista fu illesa trovata dal fuoco, che fu grandissimo miracolo a tutta la terra.' The combustible gases of the spring in Campo S. Polo were examined by Kauer and Bizio; Sitzb. k. Akad. Wiss. Wien, 1862, XLIV, 2. Abth., pp. 69, 70.

palace; it is very slight, and the statements as to its extent are conflicting. But there can be no doubt that the repeated displacement of the river-courses and their steady advance towards the sea must lead to some local disturbance of the sea-level. Any diversion of the rivers from the lagoons towards the south, and any improvements at their mouths, such as those made in this century at Malamocco, must bring about a closer approximation of the sea-level to that of the Adriatic, or, that is, to a slight negative displacement, while any neglect of these works might result in a slight positive displacement. If we possessed really exact information extending over some centuries, as to the true mean level of the lagoons at various times, then the influence of the regulating works would certainly find expression in the record.

Ravenna is also built on piles; parts of the floors of ancient buildings are said to lie below mean tide, a fact susceptible of the same explanation as in the cases just discussed [1].

We are thus led to the following results: from time to time parts of the alluvial land give way; the lagoons contain sometimes more, sometimes less water, but the position of the ancient bars shows that these oscillations are not cumulative in their effect, and that no important displacement has occurred.

5. *The Dinaro-Tauric coasts of the Mediterranean.* While the whole of the western Mediterranean from the Syrtis minor to Gibraltar lies within one of the Eurasian arcs, the eastern is divided into two moieties: a northern, which belongs to the Dinaro-Tauric arc; and a southern, which belongs to the northern border of the desert table-land. The northern moiety is thus built on the Pacific type, the southern on the Atlantic; the northern includes Crete and Cyprus; the southern, which is the foreland, is represented by Malta; and the two moieties stand in the same relation to each other as the Caribbean sea to the gulf of Mexico. In America, however, it is the northern part which is the foreland, and the delta of the Mississippi, through which waters of the plateau are discharged, corresponds to the delta of the Nile.

[1] The Spicilegium historiae ravennatae (in Muratori, Scriptores Rerum Italicarum, I, 6, p. 568) writes thus on the subject of the structure of the temple of Galla Placidia (A.D. 426): 'Iterum Augusta sudibus locum implet super quos lapidea fundamenta componit. Erat enim palustris locus qui sua mobilitate structuram lapidum non admittebat.' Vitruvius, ii. 9, writes on the piles: 'Est autem maxime id considerare Ravennae, quod ibi omnia opera et publica et privata sub fundamentis eius generis habent palos' (cf. supra, p. 8, note 1). Further expressions of doubt occur in von Hoff, Geschichte der natürlichen Veränderungen, I, p. 467 et seq., in particular p. 469: 'The supposed facts concerning the rising of the Adriatic sea are not all so definitely confirmed as some Italians have wished to represent them, and other learned men of this country who had an equal opportunity of observing them, and had equally eyes to see them, have directly denied their existence.'

A comparative study of seismic shocks felt at sea has led E. Rudolph to the conclusion that these, like seismic and volcanic phenomena in general, are much more frequent off coasts constructed on the Pacific type than on the Atlantic; and this applies not only to the coasts of the Ocean, but also to the Dinaro-Tauric region of the eastern Mediterranean, for this is much more disturbed by earthquakes than its foreland; in like manner the arc of the Antilles suffers much more than the gulf of Mexico[1]. This important result requires some slight qualification, but only in so far as that part of the foreland adjoining the Tauric chains along the great fractures of Syria and beyond to the Dead sea is a region of frequent shocks. In general, however, the contrast between the two regions is clearly marked, and a striking example is afforded by the repose of Egypt as contrasted with the frequent concussions in the Greek archipelago.

It is convenient, therefore, to separate these two regions, and we will consider first the Dinaro-Tauric moiety, that is, the coasts and islands which extend from Trieste to Antioch.

For this region we possess the masterly work of Puillon de Boblaye on the coasts of the Peloponnesus, a work which though somewhat antiquated is a model of exact observation and unbiased inference; we have also numerous scattered contributions; and recently two important and closely connected regions, the Greek archipelago and the coast of Lycia, have been described by Cold and Tietze respectively[2].

On all these coasts the rivers are constantly transporting and depositing their sediments, and large tracts of new alluvial land are in active growth. This is the case from the mouth of the Narenta to the harbour of Tarsus, already silted up in the time of the Romans. The writers of antiquity were well acquainted with these facts. 'It seems clear to me,' Herodotus remarks (ii. 10), 'that the interval between the ranges of hills beyond the city of Memphis must at some time have been a bay of the sea; precisely resembling in this respect the land about Troy, and Teuthrania, and Ephesus, and the plain of the Meander, to compare small things with great; for none of the rivers which have built up these lands by their deposits can be compared, as regards size, with even one of the five arms into which the Nile is divided. But there are rivers which, though not equal to the Nile in size, have yet accomplished great works. I should like to name them; among others not the least the Achelous, which flows through Acarnania to the sea, and has already united the half of the Echinades islands with the solid land.'

[1] E. Rudolph, Ueber submarine Erdbeben und Eruptionen, Beiträge zur Geophysik, edited by G. Gerland, 8vo, Stuttgart, 1887, I, pp. 133–365, in particular p. 244.

[2] Expédition scientifique de Morée, II, 2, géologie et minéralogie, par Puillon de Boblaye et Th. Virlet, 4to, Paris, 1833, pp. 316–375; C. Cold, Küstenveränderungen im Archipel, 2. Aufl., 8vo, München, 1886, map; E. Tietze, Beiträge zur Geologie von Lykien, Jahrb. k. k. geol. Reichsanst., 1885, XXXV, pp. 367–384.

Thucydides, Strabo, and Pausanias speak of the formation of land by the Achelous. The river has been building out to sea for centuries, and thus the broad lagoon of Missolonghi has arisen. Boblaye thinks it will not be long before the current of the gulf of Lepanto sets a limit to the growth of the land.

Similarly the Sperchios has slowly and steadily built up the plain of Thermopylae, and the narrow pass is a pass no longer[1]; in this way the harbour of Milet has been filled up, and the island of Lade, lying in front of it, united with the mainland by the Meander; and so, finally, by the unceasing work of the rivers all those new tracts of land have been formed which may be seen on the south coast of Asia Minor, but these it is scarcely necessary to enumerate.

Not long ago a theory was advanced that all the great deltas are situated over subsiding areas; the discovery of peat and trunks of trees at a great depth in the deltas of the Po, the Ganges, and the Nile was adduced in its support. Since, however, deltas grow forward sometimes by the formation of alluvial ridges on which the river flows, and at others by the spreading out of sheets of sediment, it is evident that such remains as these may be deposited at great depths without any change in the level of the strand. On the other hand, deltas have lately been regarded as indications of elevation, but no sufficient evidence has been advanced in favour of this theory[2]. I confess that I find it difficult to discover in these formations anything else than the undisturbed progress of those activities, which were familiar to Herodotus more than twenty-three centuries ago, and to Strabo, who nearly nineteen centuries ago observed and described them with the greatest accuracy and perspicuity. Their growth may be hastened by deforestation, but they are proofs neither of positive nor negative displacement of the strand; all that they indicate is a state of repose.

In numerous localities recent shell beds are known, which contain fragments of pottery; they are no doubt ancient kitchen middens. Further, perforations made by boring shells may be seen in Greece at various heights above the sea; in Asia Minor also such perforations are known to occur, as at Marmaridje, north of Rhodes, at a height of more than +10 meters[3]. I can find no reference to the presence of these borings in works of human construction, and I believe that here, as in Italy, they date from pre-

[1] W. Vischer, Erinnerungen und Eindrücke aus Griechenland, 2. Ausg., Basel, 1875, p. 637 et seq.; Bittner, Denkschr. k. Akad. Wiss. Wien, 1878, XL, p. 19, pl. I, fig. 1.

[2] R. Credner, Die Deltas, ihre Morphologie, geographische Verbreitung und Entstehungsbedingungen; Peterm. Mitth., 1878, Ergänzungsheft No. 56.

[3] C. Texier, Asie Mineure, in L'Univers Pittoresque, Histoire et description de tous les peuples, 8vo, Paris, 1862, p. 34. The statements as to oscillations on Paros are not proved; cf. Tietze, Verh. k. k. Geol. Reichsanst., 1887, pp. 63-66.

historic times. Indeed, with the exception of Crete, I know of no locality which has furnished evidence of any negative movement whatever within the Dinaro-Tauric region. The volcanic ejectamenta of Santorin have no relevance to this question.

At many places on the coast of Greece and Asia Minor ruins and monuments may be seen standing wholly or in part under water. They have been regarded as so many proofs of positive movement, but I think we shall be able to show that a better interpretation for them is furnished by the writings of antiquity.

In the summer of 426 B.C., when a devastating earthquake affected the shores of the gulf of Mali (bay of Zeituni), the alluvial land on which the town of Skarphia was built broke away from the foot of the mountains and sank into the sea. In 373 B. C., under similar circumstances, the coast land on which Helike stood separated itself from the harder rocks, and the town with its whole population was swallowed up by the sea. Neumann and Partsch have collected some very instructive accounts of these events from the writings of ancient authors. Aegion, situated near the submerged Helike, was visited by an earthquake in A. D. 23, and again in 1817 and 1861. Julius Schmidt has described in great detail how during the earthquake of December 26, 1861, the whole mass of alluvium separated from the older formations along a fissure thirteen kilometers in length, and gliding down was engulfed in the sea[1].

So, too, in July, 1688, Smyrna, and in particular the Turkish fort at the entrance of the harbour, was submerged, and in the same way the alluvium of Mytilene gave way during the earthquake of 1867[2]. This, indeed, as Boblaye truly remarks, is the common history of all those towns and harbours on the coasts of the Peloponnesus, the ruins of which are visible beneath the sea, as at Epidaurus, in the vicinity of cape Skili, and of Nauplia, as well as various other places. It is the same process as, in the earthquake of 1783, separated along a fissure several miles in length the Tertiary land of Calabria from the ancient mass of Aspromonte, as during the same year caused the harbour walls of Messina to sink into the sea, in 1755 the great quay of Lisbon, and in 1692 the harbour foundations and warehouses of Port Royal in Jamaica. Such subsidences depend on many circumstances—on the steepness of the rocky slopes against which the alluvial land rests, on the nature of the alluvial land itself, on the underground water, on the mass and distribution of the load due to buildings and other constructions, and finally, on the intensity and

[1] C. Neumann und J. Partsch, Physikalische Geographie von Griechenland, 8vo, Breslau, 1885, p. 321 et seq.; J. Schmidt, Studien über Erdbeben, 2. Ausg., 8vo, Leipzig, 1879, p. 78 et seq.

[2] Fouqué, Rapport sur les tremblements de terre de Céphalonie et de Mételin en 1867, 8vo, Paris, 1867, pp. 11, 13.

direction of the shock; it is even conceivable that it is not the shock itself, but the transitory unloading of the submarine slope due to the passage of the seismic wave, which produces the effect. Such a subsidence may indeed occur simply through overweighting, and independently of any earthquake, as happened at Zug in Switzerland, where the alluvium slipped down on the margins of a lake. None of these phenomena, however, are dislocations of the rocky crust of the earth, and they have no connexion with oscillations of the strand-line.

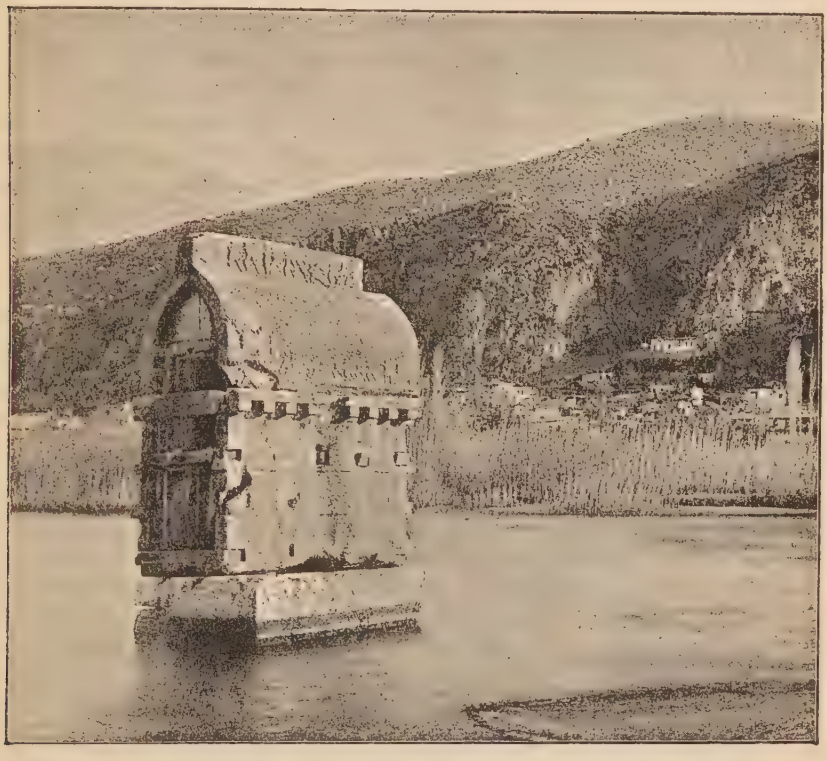


FIG. 41. *The Mausoleum in the Bay of Makri.* After a photograph kindly communicated by Dr. F. von Luschan.

The indications of subsidence recorded from the south coast of Asia Minor appear to have the same origin.

The best known example is afforded by the *bay of Makri.* Fellows describes a great mausoleum standing here in the midst of the water (Fig. 41), and observes that a daily rise and fall of the water level is visible on the side of the tomb; this is caused by a regular change of the wind, and affects a zone of about two feet. Fellows further points out that not only is one side of the mausoleum broken open, as is the case with most monuments of the kind which have been visited by treasure-seekers, but the

massive cover has been displaced to one side, and from this he concludes that the subsidence of the tomb is the result of an earthquake. Spratt and Forbes, on the other hand, referring to the same monument, state that it has been bored by marine animals up to a third of its height, showing that the ground on which it stands once lay considerably lower than at present, and that it is now probably rising. This would indicate oscillation of the strand. But Dr. F. von Luschan, who has examined the tomb with very great care, kindly informs me that the description given by Fellowes is correct, and that borings by marine animals are not to be seen. This instance is therefore susceptible of the same explanation as that found for the subsided buildings on the coast of Greece [1].

In the latest general account of the evidence presented by the coast of Lycia, von Luschan enumerates the following cases: the mausoleum of Makri just mentioned, which stands in the water near Kekova, the submerged coast road on the Klimax, and submerged foundations in Sandshakly and around Kekova, as well as at Tristomo on the island of Kekova. The statements which have been made as to negative movement or elevation of the ground rest on insufficient evidence [2].

With regard to the coast road on the Klimax, Luschan says we must conclude that in the time of Alexander it was possible with a favourable wind to march along the coast; at present this is no longer the case; twice the road ascends to a height over steep cliffs. Observations made

[1] C. Fellows, An Account of Discoveries in Lycia, 8vo, London, 1841, pp. 112, 113, fig.; by the same, Travels and Researches in Asia Minor, &c., 8vo, London, 1852, p. 302, fig.; Spratt and Forbes, Travels in Lycia, Milyas, and the Cibyratis, 8vo, London, 1847, II, p. 189. Dr. Luschan writes: 'In the present case it certainly appears as though Spratt and Forbes, otherwise very trustworthy and acute observers, have been mistaken; I at least failed to discover a single place on the mausoleum which could be described as "bored by marine animals." The strange statement "to a third of its height," which leaves us ignorant whether the height referred to is its entire height above the surface of the water, or the height of the Soros proper, the tomb beneath the cover, shows that the observation in question was made in a hasty and superficial manner not usual in these authors. I feel convinced that the mausoleum is uniformly weathered, certainly more on the windward than on the opposite side. I have never seen rocks bored by marine animals, and therefore do not venture to give a definite opinion, but I have examined the mausoleum, particularly as regards these borings, with the book by Spratt and Forbes in my hand, and I could find absolutely no other holes than such as are everywhere produced by erosion in the limestone of Lycia. Fellows' explanation of the strongly weathered dark band at the existing water level appears to me entirely satisfactory; it certainly corresponds to the *existing*, more or less, regular oscillations of the water level.' Dr. Luschan estimates the submerged part at 2·1 meters at least, to which we must add the original height of the structure above the water. Tietze unfortunately has only seen the mausoleum from a distance; Beiträge zur Geologie von Lykien, p. 294.

[2] I borrow these statements from the proof sheets of Reisen in Lykien und Karien, Bd. II, p. 46, note 2, placed at my disposal by the great kindness of Petersen and F. v. Luschan.

at low water in January, 1885, show that 'the sandy ground at the foot of these steep cliffs, which formerly offered a practicable road, is now covered by the sea to a depth of four meters.'

All these examples of positive movement are of the same nature as those local spasmodic subsidences which we have described as affecting the coasts of Greece.

Benndorf and Niemann mention submerged walls at some other points also, and in addition great rectangular excavations hewn in the rocky coast about Kekova and in Jali bay, 'immediately above the surface of the water and extending below it'; these are believed to be quarries[1]. Tietze shares this opinion, and thinks that they indicate positive movement. The purpose of these works is not known; in Egypt also, near Alexandria, in the consolidated calcareous sands of the outer bar at the mouth of the Nile, similar rectangular excavations are to be seen which extend some distance beneath the sea; but in this region a sensible displacement of the strand has certainly not taken place.

Thus as regards the coasts of Greece and Asia Minor the observations at our disposal do not enable us to recognize with certainty any displacement of the strand-line within the historic period. The indications of positive movement are probably everywhere the result of subsidences of the alluvial land which rests against the rock; indications of negative movement during the historic period are altogether absent.

On the other hand there are definite signs of a very long continued repose. These consist of a plain of erosion and a line of sea caves which are to be seen at many localities along the existing coast, particularly in the Peloponnesus.

The coastal zone, which is exposed to the influence of the waves and surf, has been admirably described by Boblaye[2]. This region is termed the *aura marina*. Its characters appear most clearly where the hard limestone formed a rocky shore, and at such places a vertical series of several zones of different colour may be distinguished. Close above the breakers lies a dark band; roughness, fissures, and cavities increase its sombre hue; its lowest part is covered by a green film. Above this band follows bare rock, in colour dazzling white, sometimes also reddish or yellow; above this is a grey zone; here the first green patches of vegetation begin to appear; finally, above the extreme limits reached by the waves, which seldom ascend higher than thirty-five or forty meters, there begins a continuous mantle of vegetation. The restricted tidal zone which lies beneath these coloured bands is hollowed out in the shore. It extends some meters

[1] O. Benndorf and G. Niemann, Reisen in Lykien und Karien, fol., Vienna, 1884, p. 28. I am indebted to Hofrat Benndorf for much kind information on this subject.

[2] Expédition scientifique de Morée; II, 2: Géologie et Minéralogie, par Puillon de Boblaye et T. Virlet, pp. 337–346.

above and below mean tide. Its submerged part is a plain of erosion which at first slopes very gently out to sea, and then plunges abruptly to a great depth. In the hard limestone its breadth is rarely so much as four or five meters, but in softer rocks it is much greater, i. e. at Marathonisi, where the Tertiary beds have been so far washed away that a steep cliff has been formed sixty meters in height, and from the foot of this a man may walk out to sea for 200 meters without getting out of his depth; this is also the case near Aegina, and particularly near Modon, where at a distance of 200 meters from the shore the sea bottom sinks rapidly into deep water. Where, as near Nauplia, the shore consists of breccia or conglomerate the waves may undermine it to the extent of eight or ten meters. The cliff thus comes to be undercut, overhangs, and is pierced by rows of sea caves.

In the zone of erosion off cape Grosso, between the bay of Messenia and the gulf of Laconia, there is a line of larger and smaller caves which so frequently communicate with one another that the coast appears to be almost continuously undercut; the sea rushes into them with a roar like distant thunder. This is the promontory which even in ancient times was known as the *Thyrides* or *Gates of the Coast*[1]. Similar caves also occur at cape Matapan, on the rocky island in front of the harbour of Navarin, and at other places. These sea caves are different from those formed in the same limestone by percolating water; they are never divided into stages, but if joints are present may attain a not inconsiderable length; their floor never extends far beneath the sea. Under such circumstances a long-continued stability of the strand-line must be inferred.

In Asia Minor we meet again with similar features. Scherzer remarks that in the bays of Agrilia, Sika, and Kalamaki, on the south side of the peninsula of Tshesme, outside the gulf of Smyrna, 'the cliffs are undercut by the play of the waves to the extent of several feet, so that some isolated rocks look as though they had a head and neck, and give proof that the sea-level has remained unchanged for many thousands of years[2].' Herr Bukowsky, who gave particular attention to this question when studying the island of Rhodes, informs me that he could nowhere find traces of movement belonging to the historic period, but in some localities he observed that the undercut part of the cliff corresponded with mean-tide level. Professor Benndorf has drawn my attention to the fact that the lagoon in which the fish oracle of Apollo Surios had its seat near Sura, north-east of Kekova, may perhaps still be recognized, though now silted up. The spring mentioned by Artemidor and Pliny is still visible near the ruins of the temple; it flowed into a lagoon, in which by cutting through the bar the fish, as they entered

[1] Strabo, viii. 2. 2, 4. 4, 5. 1; Boblaye, op. cit., p. 339.
[2] C. v. Scherzer, Smyrna, 8vo, Vienna, 1873, p. 5, note.

from the sea, were made use of for purposes of the oracle in the same way as elsewhere for capture[1].'

If we follow on the map the site of the subsidence of the alluvial deposits of Mytilene in 1867, and of the subsidence at Smyrna in 1688, the undercut shore on the south side of the peninsula of Tshesme, the Pholas borings at Mermeridje found at a height of over ten meters, the undercut coast of Rhodes, and finally, the submerged base of the mausoleum of Makri, we see clearly from the position of these localities how alleged traces of positive and negative movement follow each other in close alternation along the coast. The borings of Mermeridje can alone be regarded as genuine indications of a change in the level of the strand-line, but these must date from a time long prior to the historic period; within the historic period there is absolutely no evidence of a displacement either positive or negative; on the contrary, the character of the strand both here and in Greece points to a long-continued repose.

Wiebel believes that the existence of ancient buildings beneath the sea-level in the bay of *Samos* may be explained by subsequent sinking of the strand after violent earthquake shocks. He describes the caves on the coast of Cephalonia, in which the same singular effects of illumination are produced as in the Blue Grotto of Capri, and concludes that 'all these caves, the floor of which lies below or only a little above the sea-level, have certainly been formed solely by the action of the waves[2].

It would be a useless repetition to cite all the several cases in which the submerged remains of walls and mosaic floors, on the Dalmatian coast especially, have been adduced as indications of positive movement[3]. Dalmatia has frequently been visited by violent earthquakes; I will only mention that of Ragusa which occurred on April 6, 1667[4]. During the shocks the alluvial land on the coast was disturbed and in places sank into the sea, as in Greece and Asia Minor.

Officers of the Austrian Navy have informed me that at some places the limestone cliffs on the coast of Dalmatia have been deeply undercut,

[1] O. Benndorf and G. Niemann, Reisen in Lykien und Karien, I, p. 31, note 1; II, p. 46, note 1.

[2] K. W. M. Wiebel, Die Insel Kephalonia und die Meermühlen von Argostoli, 4to, Hamburg, 1874, pp. 45, 47. Fouqué has given a simple explanation of sea colks in his work on the earthquakes of Cephalonia quoted above.

[3] Von Hoff, Kloeden, and Morlot have collected examples of this kind; the last enumeration is contained in Bol. R. Com. geol. Ital., 1874, V, pp. 37–60. Hofrat von Waniek, director of the maritime works at the mouth of the Nabresina, told me that he had met with no signs of a recent alteration of the strand in this region.

[4] During this earthquake peculiar movements of the sea occurred; an eyewitness writes: 'Ritirossi il mare, che per due braccia di altezza tre giorni stette fuori del suo naturale'; Lettera de P. Vitale Andriasci, Min. Oss., Ragusa, 16 April 1667, reprinted in L. Stulli, Sulle detonazioni dell' Isola di Meleda, altera lettera, 8vo, Bologna, 1828, pp. 52–54.

but at the level of mean tide. I am indebted in particular to Fuchs and von Milíc, ensigns of the Royal Imperial Navy, for a detailed description of the Pettini di Ragusa (Fig. 42). A ridge of rock jutting out into the sea has been worn into a number of comb-like denticulations; the first tooth is cut out at the level of mean tide, and rises to a height of −0·1 meter; the second reaches the same height; the third and fourth are shown in the illustration (Fig. 42). The undercut cliff also surrounds all the succeeding teeth; it has not been formed by the action of the waves, which ascend much higher, but lies in a zone where the sea-level daily rises and falls in continual and gentle oscillation.

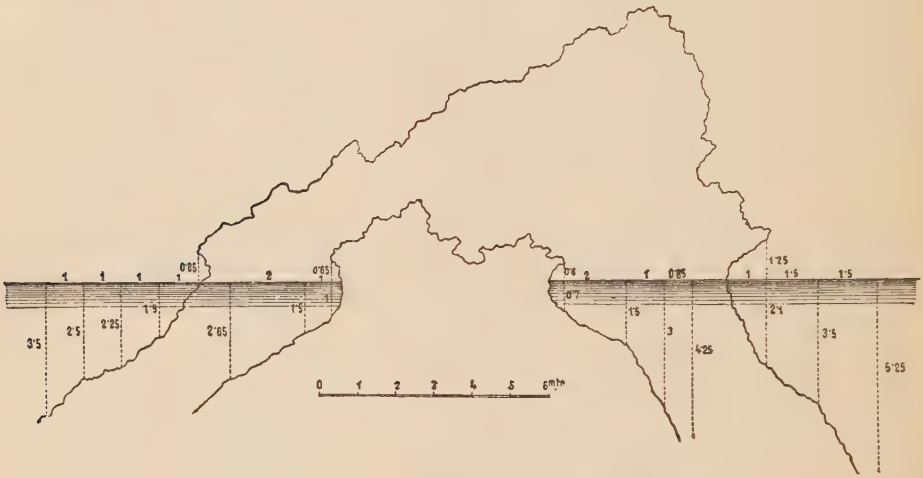


FIG. 42. *The third and fourth teeth of the Pettini di Ragusa.*
(According to the measurements made by Herr von Milíc, ensign of the Royal Imperial Navy.)

6. *The south-eastern Mediterranean.* After the analysis of the data relating to the coast of Syria by Diener, I cannot admit that any change of level within the historic period has been definitely established for that region[1].

The Dead sea lies in a fault-trough which extends northwards as far as the Great Hermon, and consequently embraces the whole valley of the Jordan, together with the lakes of Tiberias and Huleh (I, pp. 368–386). The important work of Diener has shown that north of the Great Hermon the Bekáa forms a second trough joining that of the Jordan and striking to the north-north-east, that Lebanon and Anti-Lebanon are horsts, and that the great fractures, which determine the structure of the land, separate in virgation east of the Anti-Lebanon.

[1] C. Diener, Libanon: Grundlinien der physischen Geographie und Geologie von Mittel-Syrien, 8vo, Vienna, 1886, pp. 90–103.

The Dead sea, the level of which stands at −392 meters, sinks on its east shore to a depth of 400 meters, and lake Tiberias, with a level of −212 meters, is 250 meters in depth. Around this lake Lortet has discovered terraces, which extend up to the existing level of the Mediterranean, and include the whole valley of the Jordan together with the Dead sea. Hull has also met with terraces on the south side of the Dead sea up to about the same height, and has shown that the uppermost of the southern terraces and the higher terraces of the Jordan valley contain living species of Melania and Melanopsis; Noetling, likewise, has found existing species of Melania in the continuation of the same alluvium on the south side of lake Tiberias, and has even discovered them beneath one of the basalt flows which descend from the Djolan[1].

Hull correctly infers from his observations that a single continuous inland lake must have extended from lake Huleh on the north into the valley of the Arabah on the south for a distance of over 300 kilometers. Noetling, however, has shown that at a later period basaltic lava from the Djolan flowed into the trough between lakes Huleh and Tiberias, and that this flow was afterwards cut through by the Jordan.

We may speak of this great inland water as the *Jordan lake.* It was 800 meters deep. Fresh-water mollusca lived on its shores; and up to the present day fish belonging partly to the fauna of the Nile, and partly to that of the Euphrates, have maintained their existence in lake Tiberias. The beds of gypsum and salt of Jebel Usdom began to be formed as evaporation became accelerated; with the fall of the water level the lake became separated into two; in the depression between lake Tiberias and the Dead sea the course of the Jordan arose, and finally, in the region of the deepest hollow, the briny residuum of the Dead sea was left behind.

In this way those horizontal terraces and strand-lines of the ancient lake Jordan were produced which extend in a meridional direction for nearly two and a half degrees. These terraces are due not to telluric movement, but to excess of evaporation. All observations hitherto made point to the conclusion that the sea has never found an entrance into this fault-trough. We do not know, it is true, whether the highest strand-lines of lake Jordan are precisely on the level of the adjacent Mediterranean. If such a correspondence as exists has been brought about by the discharge of the waters of the lake into the Mediterranean, we should be justified

[1] E. Hull, Mount Seir, Sinai, and Western Palestine, 8vo, London, 1885, pp. 100, 106; and by the same, The Survey of West Palestine, 4to, London, 1886, p. 79 et seq. Hull was the first to show that the Salt mountain, Jebel Usdom, really belongs to the recent formations of the Dead sea. F. Noettling, Geologisch-paläontologische Mittheilungen aus Palästina, I: Ueber die Lagerungsverhältnisse einer quartären Fauna im Gebiete des Jordanthales, Zeitschr. deutsch. geol. Ges., 1886, XXXVIII, pp. 807–823; and Geologische Skizze der Umgebung von el-Hammi, Zeitschr. deutsch. Palästina-Vereins, X, pp. 59–88, map.

in concluding that the level of the Mediterranean has not sensibly changed since the formation of the great trough, nor during the period of evaporation through which this region has passed. On this point we must await further observations.

We will now enter the table-land which extends between the Dead sea and the Nile.

We have already mentioned that Hull found the traces of an ancient strand near Suez at a height of about 200 feet (60 meters), that this level very nearly coincides with the height of 64 meters which Schweinfurth assigns to the upper zone of Pholas borings on the Mokattam hills near Cairo, and that Zittel gives 64 meters as the height of the marine deposits near the Pyramids of Ghizeh. These closely corresponding figures were obtained for the shores of a sea whence a few Erythraean species crossed into the basin of the existing Mediterranean (I, pp. 379, 380). Near Ghaza, Hull mentions marine beds at a height of 200 to 220 feet (60–67 meters)[1]. Schweinfurth has lately met with the same deposits at the same height of 60 to 70 meters near Ssedment in the Nile valley (lat. 29° 20′ N.), and thus placed beyond doubt a conjecture frequently entertained that this valley had once been occupied by the sea[2].

Thus the whole of lower Egypt is surrounded by traces of a sea, the deposits of which rise from 60 to 70 meters above the existing surface of the Mediterranean, and below these traces of the ancient strand extends the alluvial land of the Nile, where man may look back further than at any other spot into the past history of his race. But all the most ancient records of Egyptian civilization, and all the still older remains of the stone age which are found in the same region, are more recent than by far the greater part of the fluvial land, and consequently incomparably more recent than the traces of the ancient sea; all the thousands of years of human history give no parallax of time, not even the remotest indication which would help us to number the ages during which the hydrographic conditions of this country have remained essentially the same as at the present day.

These conditions are of a very peculiar nature.

West of the Nile and the town of Ssedment mentioned above, the depression of the Fayûm lies in the desert, separated from the river valley only by a narrow ridge. In its north-western part lies Birket-el-Qerûn,

[1] Hull, Survey of West Palestine, p. 74. Further north marine deposits were encountered up to 250 feet (76 meters) and even higher; cf. C. Post, On a Deposit of Marine Shells in the Alluvium of the Latakia Plain in Syria, Nature, 21 August, 1884 (XXX); but Diener assigns a greater age to them, Libanon, p. 101.

[2] G. Schweinfurth, Reise in das Depressionsgebiet im Umkreise des Fajûm im Januar 1886; Zeitschr. Ges. f. Erdk. Berlin, 1886, XXI, p. 100. The mollusca of the neighbourhood of Ghizeh are enumerated by Mayer-Eymar, Zur Geologie Egyptens, Vierteljahrschr. Naturf. Ges. Zürich, August, 1886, XXXI.

the remains of the ancient lake Moeris. In April, 1885, its level stood 40 meters below that of the Mediterranean; it is now slowly rising. The chief town Medinet-el-Fayûm, near the ancient town of Arsinoë (Crocodilopolis), lies on a terrace at a height of 23 meters. The narrow ridge between the Nile valley and the Fayûm was cut through in ancient times to afford an ingress into the depression for the waters of the Bahr Yusuf (Joseph's Canal) which branches off, far above, from the main stream. West and south-west of the Fayûm are other tracts of the desert lying beneath the level of the sea; in recent times they have been designated by the general name of the Rayân; this is the middle part of the depression; it reaches a level of −19 to −20 meters. Cope Whitehouse regards the Rayân rather than Birket-el-Qerûn as the site of the ancient lake Moeris[1].

El-Lahun, in the Nile valley, is situated on the alluvial land, where the Bahr Yusuf enters the Fayûm (at a height of about 27 meters). A little to the south of it the marine deposits of Ssedment occur, as we have seen, at a height of 60 to 70 meters, but Schweinfurth has not been able to trace these marine deposits anywhere into the Fayûm or Rayân, the borders of which seem to be formed of fairly horizontal beds of lower and middle Tertiary age. We must therefore conclude, pending further information, that these two subsidences are related to one another in the same way as the shotts west of Gabes, and the region of the Jordan. The relict strand-lines extend from the Mediterranean nearly to the summit of the threshold of Gabes, and yet in the shotts which sink below the existing level of the sea no traces of a recent marine submersion are visible. For this reason the inbreak is regarded as of no great age (I, p. 359). We met with the same phenomenon on lake Jordan; it recurs, as existing observations would seem to show, in the Fayûm and the Rayân; for these depressions can only be interpreted as subsidences.

In the Rayân Schweinfurth encountered no recent marine or fresh-water sediments; in the Fayûm pale grey fresh-water marls with Melania and fish remains reach a height of about forty meters above the lake, that is, almost up to the level of the Mediterranean. Medinet-el-Fayûm, however, stands on a deposit of Nile alluvium which has been carried into the depression by the Bahr Yusuf. Ancient buildings of great size appear to have been buried under this accumulation in the course of the last few thousand years. The Bats, the northern of the two principal branches into which the Bahr Yusuf divides after it has entered the Fayûm, has excavated its bed seventeen meters deep in its own alluvia.

We have now reached the site of one of the most magnificent works ever executed by the hand of man. The overflow of the high-water Nile

[1] Cope Whitehouse, The Bahr Jûsuf and the Prophecy of Jacob; Proc. Soc. Bibl. Arch., Nov. and Dec., 1885, with maps, et passim.

was conducted from the Bahr Yusuf through the canal of Menhy, which was furnished with sluices to the west and formed lake Moeris; lower Egypt was thus protected from floods, and at the same time a part of the desert was converted into a marvellous garden, famous many thousands of years after the work was completed for its vines, roses, and olives. On the canal lay the richly adorned and extensive structures of the labyrinth with its flat roofs formed of great slabs of stone. Not far from the existing Medinet-el-Fayûm, where the ruins of Arsinoë (Crocodilopolis) lie, there rose on a space surrounded by the lake the temple of the crocodile god Sebak; crocodiles and a great abundance of fishes inhabited the lake.

We can readily understand and indeed share the admiration with which Herodotus, Strabo, Diodorus, and Masûdi speak of these works. The Egyptian manuscripts which have been freshly explained by Pletje represent the Menhy canal as divided lengthways down its middle. On one side fish enter, on the other they leave. They all belong to the same species, which Dr. Steindachner recognizes from the description as *Mormyrus cachive*, Geoffr.; it is still common in the Nile. In addition to the fish which mark the course of the water, we see a band of marsh-dwelling birds, outside this a band of trees, and outside this again (as shown by a second papyrus) the forty-two temples standing on the two sides of the river; each temple corresponds to one of the forty-two Nomes of upper and lower Egypt as far as the nineteenth Nomos of Pelusium, at the eastern end of the delta, where at the present day the steamships from the Mediterranean enter the Suez canal at port Said. A third manuscript relates the creation of the lake; it was 52½ kilometers long and 5½ kilometers broad; the Birket-el-Qerûn represents its existing remains [1].

'The waters of this lake,' says Herodotus, 'are not the spontaneous production of the ground, which is particularly dry in this region; they come from the Nile through a canal and flow six months from the Nile into the lake, and six months from the lake into the Nile; during the six months after the discharge begins the lake daily brings the royal treasury a talent in silver as the value of the fish; but at other times the daily value is only twenty minae. The inhabitants of the country tell me also that the lake empties its waters into the Libyan desert by a subterranean channel which runs westwards towards the interior, along the bend situated above Memphis [2].' The westerly position would correspond to the Rayân.

Such was the beneficent character of the national treasure with which

[1] W. Plejte, Over drie handschriften van papyrus bekend onder de titels van Papyrus du Lac Moeris, du Fayoum et du Labyrinthe, Verh. K. Ak. Wetensch. Amsterdam, Afd. Letterk., 1886, XVI, pp. 1–50, pl.

[2] Herodotus, Euterpe, ii. 149, 150.

Amunemha III of the twelfth dynasty, 'the well-beloved of Sebak, the lord of the island of beauties,' presented his people. Its chief features, namely, the formation and maintenance of the Bahr Yusuf, the turning aside of this branch of the Nile towards the desert, and the worship of the crocodile on the island of a lake abounding in fish, we recognize without difficulty in the expressions of the prophet Ezekiel (xxix. 3–5), which Dr. Adolf Beer has been kind enough to translate literally for me as follows:—

3. '*Lift up thy voice and speak, thus saith the Lord, the Eternal: I come against thee, Pharaoh, King of Egypt, thou great crocodile (animal of the lake), who lieth in his rivers and sayeth: Mine is the river, and I have made it for myself.* 4. *And I put a ring in thy jaws, and hang the fishes of thy river in thy coat of scales, and I draw thee out of thy river, and all the fishes of thy river which hang on thy coat of scales.* 5. *And I abandon thee to the desert, thee, and all the fishes of thy sea, and on the plain thou shalt lie, neither taken up nor gathered together. . . .*'

St. Jerome has compared this passage with that of Isaiah xix. 5, 6: '*Et arescet aqua de mari, et fluvius desolabitur atque siccabitur et deficient flumina, . . .*' and concludes that it is not the open sea which is meant here, but the lake Mareotis[1]. The passage refers to the great national work of the Egyptians at lake Moeris, as is shown by the mention of the crocodile (animal of the lake) and the fishes, and in particular by the words, '*Mine is the river, and I have made it for myself.*'

When Strabo visited this region, about the year 23 B.C., he was still able to be present at the feeding of the holy crocodile, and praised the excellent oil and the fertility of the Nomos of Arsinoë[2]. To-day the fertility is no more, the servants of Sebak have disappeared, but the Bahr Yusuf still exists and still flows towards the depression in the desert lying to the west. The forty-two Nomes which once worshipped their gods near the canal of Menhy comprised all the country as far as the shores of the Mediterranean, and nowhere is any other change of level to be seen except such as has been caused by the increasing thickness of the Nile mud, or by the accumulation of sand. We must therefore admit that this fragment of the earth's crust has maintained its stability throughout the whole period.

The lowland below Memphis was formed by the advance of the main branches of the river into the bay on self-constructed dams, a process now taking place on the Mississippi. While the dams were being extended further and further forwards, the spaces on their inner side were silted up, and so the delta originated. But the pushing forward of the dams was not the only process. The fresh water, lighter than that of the sea,

[1] S. Hieronymi Opera, ed. Vallars, 1735, IV, p. 208.

[2] Strabo, xvii. 1. 35, 38.

spread out sandy mud in a very flat cone, which extended for a great distance into the sea; upon and within this the dams stood. A day's journey from the land, says Herodotus, the sounding-line still brings up mud from a depth of two fathoms, for so far does the alluvium extend [1].

The sea waves, coming in over this flat cone, have washed out the sand from the mud and so built up the great crescentic spits of sand and friable sandstone which stretch from one mouth to the next, connecting them one with another, and which cut off from the sea the great lagoons, not yet silted up, extending from lake Mareotis to lake Menzaleh. In the west, as far as the ruins of Canopus, and perhaps as far as the island of Nelson opposite them, the loose sand has been consolidated into calcareous sandstone. Owing to the direction of the winds a slight movement to the east prevails; this renders possible the high salinity of the sea west of the Nile, and Spratt predicted that it would prove a difficulty in the maintenance of the Suez canal; but the formation of the spit in front of the harbour of port Said has shown that the effect is trifling [2]. Nevertheless in the course of time it has sufficed to build up long narrow bars east of the delta, extending from lake Sirbonis to the mountain of Casius, and from this still further to the east.

The mouths of the Nile present just as complicated a structure as those of so many other rivers, and here, too, we must distinguish the accumulations formed by the river, and advancing towards the sea, from the crescentic sandy bars directed across the river dams. An extremely long period was doubtless necessary to give rise to these natural growths, but as far as even human tradition extends we find them already completed and occupying approximately their existing position.

It is true that near Alexandria the sea may be seen to enter the tombs excavated in the loose sandstone of the coast, as well as other cavities, and near the coast the road may even lie here and there below the level of low tide. Fraas has given an account of these facts [3]. But Alexandria was founded twenty-two centuries ago on the site of the ancient Rhacotis, and the neighbourhood was certainly as flat then as it was subsequently when Strabo described the town, and as it still remains. Then, as at present,

[1] Herodotus, Euterpe, ii. 5. If Herodotus had travelled to Alexandria by the existing line of mail steamboats he would not have encountered this, for the west winds do not allow the mud to be carried so far west, and the great accumulation begins at the Canopic mouth.

[2] Captain Spratt, An Investigation of the Effect of the prevailing Wave Influence on the Nile's Deposits, Blue Book for 1859, with maps; A. Lavalley, Communications sur les travaux d'exécution du canal maritime de l'Isthme de Suez, Extrait du Compte Rendu de la Société des Ingénieurs Civils, 8vo, Paris, 1869, pp. 64, 80, 106, 131.

[3] O. Fraas, Aus dem Orient, p. 174 et seq. According to Wilkinson the chief square of the Frankish quarter, which lies low, is situated on parts of the harbour which have been filled up; Handbook for Travellers in Egypt, 8vo, 1867, p. 91.

there lay before the main body of the bar the famous island of Pharos, and the Heptastadium which connected the island with the bar may still be recognized. It is, therefore, impossible that a positive movement can have resulted in any important displacement in the course of this long period. Towards the north-east, where the spit projects as a promontory, and where Heracleum once stood, near the Canopic mouth, Paris landed nearly thirty-one centuries ago, and there, according to Herodotus, Helen and the treasures of Menelaus were taken from him at the command of Ramses III [1].

Through the mouth of the Bolbes the Milesians entered with thirty ships in the time of Psammetich, and through the Pelusian branch the fleet of Alexander the Great sailed towards Memphis. Thousands of years ago the fresh-water canal flowed as at present through the Wady Tumilat, and from the end of the Wady made a sharp bend towards the Red sea. If we open the works of Brugsch, Schleiden, or the many other investigators who have attempted to determine the features of the fluvial network of the delta as it existed in antiquity, we shall be constantly impressed by the fact that the plan has remained fundamentally unchanged so far as human tradition exists [2]. No perceptible elevation, bulging up, or other disturbance of the fall has occurred.

This constancy is distinctive not only of the fluvial network. It is also evident that the flat country east of Pelusium and the bar lying in front of the Lacus Sirbonis as far as the Casius (Ras-el-Kasrûn) had the same structure many thousands of years ago as at the present day. In ancient times this narrow bar afforded the chief route for traffic, indeed it appears to have been the only road between Syria and Egypt. There are numerous proofs of this. Herodotus describes the way along the coast over the Casius as the only practicable road from Phoenicia, 'and at lake Sirbonis, in which according to the legend Typhon lies concealed, Egypt begins.' Diodorus and Strabo give a particularly detailed description, and Polybius already mentions the pitfalls (*βάραθρα*) of lake Sirbonis. Diodorus further relates that Artaxerxes, on his march to Egypt, lost a part of his men in these holes owing to his want of knowledge of the country, and Strabo states that during his stay in Alexandria the sea had exceeded its limits and flooded the land, so that the mountain of Casius became an island, and the land past it to Phoenicia was navigable for ships [3].'

These pitfalls, however, as may be seen from the descriptions, were

[1] Herodotus, Euterpe, ii. 113; Schliemann, Ilios, p. 186, note; Brugsch-Bey, op. cit., pp. 819, 824.

[2] H. Brugsch, Die Geographie des alten Aegyptens, 4to, Leipzig, 1857, I, p. 84 et seq.; M. J. Schleiden, Die Landenge von Suês: zur Beurtheilung des Canal-Projects und des Auszuges der Israeliten aus Aegypten, 8vo, Leipzig, 1858.

[3] Diodorus, Bibl. hist., i. 30 and xvi. 46; Strabo, Geogr., i. 3, 13.

regions of treacherous quicksand in the lake which was in process of silting up.

It has been repeatedly maintained that it was by this road to Syria that the Israelites left Egypt. In recent times Schleiden has defended this view with much vigour[1]. The most important evidence, however, has been furnished by Brugsch, who has discovered a manuscript in the British Museum, in which an Egyptian official, three thousand years ago, reports the pursuit of two fugitive thieves; they had escaped in an easterly direction along the Syrian military road across the bar, and the same stopping-places are mentioned as in the accounts of the Israelites[2].

Thus it would seem Pharaoh Meneptah in his pursuit of the Israelites perished in the '*βάραθρα*,' in the quicksands of lake Sirbonis, where also the army of Artaxerxes suffered loss. The statement that the sea stood like a 'wall,' i.e. like a protective rampart on both sides of the people, would then signify that the Israelites went dry through the sea on the narrow bar, i.e. on the high road to Syria. For this reason the song of praise which must be regarded as the oldest account of this event (Exodus xv. 1–21), extols in a striking manner not so much the miracle of the division of the waters and the passage through the sea as the destruction of the pursuer[3].

In this way, too, the variously interpreted passage in Isaiah xi. 15, 16, perhaps finds its correct explanation; in Beer's translation it runs:

15. '*And God will cut off the tongue of the Egyptian sea, and lift his hand against the river in the violence of his anger, and smite it into seven brooks that may be traversed dryshod.*

16. '*It shall be a path prepared for the remnant of his people, those who are left of Asshur, like as it was for Israel in the day when he came hither out of the land of Egypt.*'

The tongue of the Egyptian sea must thus be understood as the bar traversed by the road which led to Syria[4].

[1] M. J. Schleiden, Die Landenge von Suês, &c., p. 177 et seq.

[2] H. Brugsch-Bey, L'Exode et les monuments égyptiens, 8vo, Leipzig, 1875, map. An example of the dangers of the sands on the inner side of the bars is given by Berendt, Geologie des kurischen Haffes, 4to, 1869, p. 22 et seq., where he tells how horses and wagons have sunk in them. Cf. Exodus xv. 5, 'The depths have covered them: they sank to the bottom as a stone'; xv. 10, 'Thou didst blow with thy wind, the sea covered them; they sank as lead in the mighty waters.' Pi ha Khiroth of the Bible means 'entrance to the abysses.'

[3] This is emphasized by Dillmann, Die Bücher Exodus und Leviticus, für die 2. Aufl. nach Knobel bearb., Leipzig, 1880, p. 153. Dillmann thinks the Israelites went over El Guis'r.

[4] The exegetes generally regard these expressions as metaphorical and interpret them in various ways; St. Jerome writes 'Et desolabit Dominus linguam maris Aegypti,' ed. Vallars, 1753, IV, p. 164; Schleiden regards lake Menzaleh as the 'tongue,' op. cit., p. 198.

Let us recall the different opinions arrived at by Spratt and Lesseps before the construction of the Suez canal, as a result of a close examination of the movement of the sand on these shores. Experience has shown that the lateral movement is slight. Nevertheless in conjunction with the waves washing vertically against the shore, it had already built up many thousands of years ago the bar in front of lake Sirbonis; this still exists, and still the waters stand like a protective rampart on each side of the ancient road. The slight positive displacement at Alexandria may easily result from a different distribution of the volume of water in the branches of the Nile.

The horizontality of the terraces of lake Jordan, the great age of the bars and spits, the unaltered fall of the natural and artificial branches of the Nile forbid us to suppose that the solid foundation land on the south-east of the Mediterranean has experienced any important change of level within the historic period.

7. *Conclusion.* There is abundant evidence to prove that the level of the Mediterranean has remained constant for the last few thousand years. The bar of Arabat in the sea of Azov, and that of Perekop, the 'Course of Achilles,' were in existence twenty centuries ago. The bar of the Mons Casius outside lake Sirbonis is known to date from a still earlier time; it was traversed at the most brilliant period of Egyptian history by the only military road which led to the east; and it was in all probability by this road that the Israelites entered the desert. The lagoon of Tunis shows that the sea-level has remained unchanged for a very long period; of equal force, and perhaps applicable to a still longer course of time, is the proof afforded by the uniform height of the foundation which bears the successive bars of Aigues-Mortes, west of the mouths of the Rhone. On the bars of Tuscany lie the remains of a Roman road; the ancient drainage channel of Cosa still serves its purpose; the Po traverses successive bars at an equal height. In many places the coast is distinguished by undercut cliffs or caves which have been excavated by the sea at its existing level. In Egypt, which affords our furthest glimpse into antiquity, the fall of the water channels, and consequently the slope of the land, has remained so absolutely constant that the Bahr Yusuf still flows towards lake Moeris on the line of the ancient canal of Menhy, and the fresh-water canal of the Nile still bears its water through the valley of the Seven Springs.

Notwithstanding these striking indications of stability, among them the undercut cliffs of rocky shores, which no observer could overlook, it has been imagined that we must assume divers elevations and subsidences of the ground. The sources of this error are of various kinds, and certainly specious. To begin with, attention was directed to relict strand-lines and Pholas borings, and these naturally suggested the idea that processes which

were active immediately before the dawn of history might be still in progress and give perceptible signs of their existence. In the next place but little was known even till very lately of what extensive areas may be covered by kitchen middens, and every shell-bed which contains fragments of pottery was regarded as a certain proof of recent elevation. Again, even the slow and gradual progress of silting up by rivers has sometimes been regarded as a mark of elevation of the land.

Furthermore, it was thought that subsidences might be recognized. When the alluvial land of the shore is shaken by an earthquake, it frequently becomes detached from its base and glides into the sea; in ancient times many towns were engulfed in this way, and even in our own days such catastrophes have occurred, for instance, in 1861, in Aigion, not far from the spot where twenty-two centuries before the town of Helike sank beneath the sea. The recurrence of similar events has not led to the conclusion that the conditions must have remained the same; on the contrary, these submerged remains of walls, particularly of harbour foundations, are alleged as proofs of a subsidence affecting the entire lithosphere. In the same way trifling changes in the level of the lagoons of Venice, as well as of those at Ravenna and Alexandria, have been regarded as indications of subsidence, although here, apart from the mobility of the alluvial land, an increased volume of the water delivered by a single arm of a river would probably afford a sufficient explanation.

In this way the curious result is obtained that rising, falling, and stable regions change places with each other along the Mediterranean coast according to no perceptible rule, positive and negative movements often occurring close beside each other several times in succession, as, for example, in the south-west of Asia Minor. Again, the evidence presented by the temple of Serapis led to the inference that within the same space elevation and subsidence may in the course of centuries succeed each other, but its exceptional position in the middle of a crater was overlooked.

A stricter inquiry removes these difficulties, and we perceive that the level of the Mediterranean has remained unchanged during the last few thousand years; if there has been any change at all, it is so slight as to be beyond the power of observation to discover it. An exception is furnished by the south-west of Crete.

The measurements on which we can base a comparison of the level in the Mediterranean with that of the Ocean, unfortunately still few in number, lead us to suppose that the form of the surface of the Mediterranean, apart from the influence of attraction, is that of a funnel, the deepest part of which lies between Crete and the coast of Africa. Every change of climate in the Mediterranean region ought to find expression in the level of its waters. In the south-west of Crete, Spratt believes he has

observed signs of a considerable negative movement; but this region must be again investigated before we can arrive at any definite opinion.

It is surprising that the frequent earthquakes which visit certain regions on the coasts of the Mediterranean have left behind no visible dislocation. I, at least, am not acquainted with any well-authenticated instance. But even the dislocation observed not long ago in New Zealand (II, p. 28) is only represented by such features as will be obliterated in the course of a few years. Should, however, some example be discovered of a genuine dislocation affecting the Mediterranean coast in historic times, yet this would not invalidate the general result of our comparative study. *The Mediterranean region has so far afforded no proof of a secular continental elevation or subsidence within the historic period.*

CHAPTER XII

STRAND-LINES OF THE NORTH

Diversity in form of the surface of the Oceans. Western coasts of the North Atlantic. Eastern coasts of the North Atlantic. The north of Eurasia and the west coasts of the North Pacific. East coasts of the North Pacific.

THE superficies of the Baltic and the Mediterranean, owing to climatic influences, possess a form which is not that of the Ocean. In the Baltic we have reason to believe that the surface falls from the most distant parts of the gulfs of Bothnia and Finland towards the Belts and the Oere sound; in the Mediterranean, on the other hand, it would appear that the place of maximum depression must lie between Crete and the coast of Africa. Even the surface of the open sea itself is not independent of such influences. The salinity is frequently less in the vicinity of the coast than in the sea remote from land; temperature and the atmosphere also affect the surface. Unfortunately actual observations on this subject are few in number, but the admirable work carried out by the Norwegian North sea expedition, and the investigations based upon it by H. Mohn, show how remarkable, even apart from attraction, are the deviations from a supposed normal surface as exemplified in that part of the sea which forms the connexion between the North Atlantic and the Arctic Ocean. In fact Mohn's graphic representation of this region shows that here also the Ocean surface presents a funnel-like form, the maximum depression occurring between Iceland and Norway. From this point the surface rises towards the coasts, particularly towards the south of Norway, so that at Christiania the rise is as much as 2·9 meters, but at Bodö and the North cape only 0·7 meter. This gives a difference in the height of the sea-level between Christiania and the North cape of 2·2 meters. Mohn adds that on the coasts themselves the sea-level may be influenced to a high degree by the retardation of the tide over a shallow bottom, by the influx of fresh water, the state of the wind and other local circumstances[1].

Thus we see how difficult it must be, under any conditions, even those of the open sea, to demonstrate a movement of the lithosphere from slight displacements of the strand-line.

The irregular form of the Ocean surface has also been shown by direct measurement.

[1] H. Mohn, Die Strömungen des europäischen Nordmeeres; Peterm. Mitth., Ergänzungsheft No. 79, 1885, pl. ii, fig. 6.

In 1837 the English Government caused a mark to be put up at Poolbeg lighthouse in Dublin bay at a certain height above low-water. Low-water level was to be the basis of the Irish measurement; but the deviations from it were found to be so great that this basis had to be abandoned and all the observations were referred to a standard point.

A summary of the observations, which were very numerous, has been made by Kinahan, who has shown that all around the island low-water as well as high-water and spring tide correspond to undulating surfaces, not to planes of equal level; this is particularly marked in the case of high-water and spring tide, which, as Kinahan justly remarks, determine the formation of terraces. The lowest mean of high-water spring tide above the lowest mean level lies near Courtown (Wexford, east coast); the lowest mean level is at Kilbaha, north of the mouth of the Shannon. If we exclude the narrow bays, in which as a matter of course still greater deviations occur, then we obtain the following result, taking the minimum near Courtown as zero :—

The mean level of high-water spring tide rises higher and higher north of Courtown until at Ardglass, opposite the Isle of Man, it reaches + 1·981 meters. From this point onwards to about the north-east corner of the island it sinks gradually to + 0·305 meter at Ballycastle opposite the Mull of Cantire. Following the coast, with the exclusion of sheltered localities, we see these figures rise again, as we pass to the west and south, until at Slyne head, the north promontory of Galway bay, + 1·59 meters is reached. Around the south-west corner, the level falls again till 0·61 meter is reached at Cork; it then ascends towards Dunmore, where it is 0·92 meter, and finally returns to zero at Courtown.

Thus the conditions which prevail around Ireland are extremely complex, and Ravenstein observes that, according to the measurement of Ross Clarke, the mean level at Rispond on the north coast of Sutherland is 0·5291 meter higher than that of Liverpool, but the mean level of Kilbaha is − 0·4395 meter as compared with that of Liverpool, and consequently the mean level at Kilbaha is 0·9686 meter lower than at Rispond [1].

In this case it is the outline of the island and the direction in which the tide impinges that mainly determine the height of the sea-level. Generally speaking, the deformations to which the surface of the open sea is subject may be regarded as less exposed to variation than is the case with enclosed seas. This of course does not hold true of bays, and probably not of the Arctic coasts, where the influx of fresh water from melting ice is in places very considerable, and where consequently great local fluctuations must be expected.

[1] Kinahan, Irish Tide Heights and Raised Beaches, Geol. Mag., 1876, 2nd Ser., III, pp. 78–83; E. G. Ravenstein, On Bathyhypsographical Maps, Proc. Geogr. Soc. London, 1886, VIII, p. 24.

With this short preface I will now endeavour to give a brief account of the recent oscillations which have affected the coasts of the open seas. The facts bearing on the subject are so numerous, and their value so different, that we must confine ourselves to a few selected examples. To begin with, the northern latitudes will be discussed, first the western and then the eastern coasts of the Atlantic Ocean, including the adjacent parts of the Arctic sea, next northern Asia and the western coasts of the North Pacific Ocean, and finally its eastern coasts. The chapter will conclude with a general survey of the results obtained in our study of these northern regions of the globe.

1. *Western coasts of the North Atlantic Ocean.* From this region we possess a number of observations referring partly to positive and partly to negative movements, supposed to be demonstrable and in progress at the present day; the latter will be considered first.

The best-known example is to be found in the alleged *tilting movement of Greenland.* In the extreme north, high-lying strand-lines have been observed and recognized as indications of negative movement, or, according to the terminology of the time, proofs of the elevation of the land. But we do not know the age of these strand-lines; some of them were doubtless only produced by a temporary closure of the fjords by ice, and they are found equally in the south, notably in the fjord of Igalliko, which contains the supposed proofs of the subsidence of the land and consequently should represent the other side of the swing.

The supposed subsidence of the land rests chiefly on the statements in a letter written by Dr. Pingel of Copenhagen in 1835 [1].

Pingel states that Arctander in 1777 and 1779 had already suspected that the west of Greenland was in process of subsidence. He had observed that a low rocky island in the fjord of Igalliko, about a gunshot away from the mainland, was almost completely submerged at high tide, and yet there were standing on it the walls of a house 52 feet long, 30 feet broad, 5 feet thick and 6 feet high. When Dr. Pingel visited the island fifty years later it was so far submerged that the ruins alone projected above the surface of the water.

Subsequently Kane observed abandoned huts, with the sea washing against them, at several localities as far north as Upernavik; the last remains of this kind would appear to occur in lat. 76° 20′ N. Kane, who knew that terraces existed in still higher latitudes and regarded them as indisputable signs of elevation, concluded, as we have seen, that Greenland was experiencing a tilting movement similar to that supposed by Lyell

[1] Letter from Dr. Pingel, Proc. Geol. Soc. London, November 18, 1835, II, p. 208; also Poggendorff's Ann., XXXVII, p. 446 et seq.; earlier references to bibliography in Brown, Physics of the Arctic Sea, 8vo, 1871, p. 690 et seq., also Quart. Journ. Geol. Soc., 1871, XXVII, p. 692.

to be affecting Scandinavia; the neutral axis was placed in about lat. 77° N.[1]

This theory has passed into several of our textbooks.

In an abandoned village, situated at the head of the ice fjord of Jakobshavn (lat. 69° 7′ N.) and said to have once borne the name of Kaja, Nordenskiöld found ancient dwellings, now chiefly recognizable from the kitchen middens which surround them; he estimated their age at 500 years at most; they lie so near the shore that, in his opinion, either the water in the fjord must have risen or the land have sunk, for it is not probable that the villagers would have chosen a site so near the sea as to leave no room in front even for a landing-place. Jensen likewise records, in agreement with a statement previously made by Pingel, that in the mission of Lichtenfels (lat. 63° 5′ N.), according to the assertion of the missionary Kleinschmidt, it had thrice been found necessary since 1789 to remove the supporting posts for the women's boats, erected on the beach, further inland; this would give a subsidence of six to eight feet for the interval between 1789 and 1878 [2].

This does not agree with the views held by Steenstrup, who has devoted so many years to the study of Greenland; he writes in 1876: 'As to the question of subsidence I cannot deny that I am fairly sceptical with regard to it. I have, it is true, seen the sites of houses destroyed by water in several places, and it cannot be denied that at some spots the houses stand nearer the water than any one would now think of building them, occasionally indeed in the water itself; but when we consider the abundant evidence in a contrary direction pointing to an unchanged sea-level, to be met with almost everywhere on the coast, I am inclined to believe that the proofs of houses having been destroyed by the sea, which are indeed undeniable, may be explained by local causes, such as a change in the currents, or other circumstances.' To enumerate all the statements of natives and colonists would not advance our inquiry. The ruins mentioned by Pingel on the little island in the Igalliko fjord are ill suited to serve as a proof of the subsidence of the land, 'for, judging from descriptions of earlier date, it is in precisely the same condition to-day as it was a hundred years ago. Now as then the water at high tide reaches the walls. . . .' In 1883, Steenstrup gave a list of such dwelling-places as were then reached by the sea or had already been destroyed by it, without drawing any final conclusion, and with a reference to the extremely rapid progress made by silting up in a number of fjords [3].

[1] Kane, Arctic Explorations, 8vo, 1857, II, p. 692; Bessels, Die nordamerikanische Polarexpedition, 8vo, Leipzig, 1879, p. 156.

[2] Nordenskiöld, Redogörelse om Grönland, p. 1017; Account of an Expedition to Greenland in the year 1870, Geol. Mag., 1872, IX, pp. 410, 413; Jensen, Meddelelser om Grönland, 1879, I, p. 34.

[3] K. J. V. Steenstrup, Indberetning om de i Grönland i Aaret 1876 foret. geologiske

We must thus leave out of account the observations which refer to high-lying strand-lines and the ruins in Igalliko fjord. Apart from these it is obvious that at many places the conditions have remained unchanged; at other localities, chiefly within the fjords or in the arms of the sea behind the islands, there is evidence of positive displacement. But we must not overlook the fact that scarcely any other coast of such great extent receives so much fresh water under such peculiar conditions; and that this influx depends on the change of climatic conditions. Judging from the observations made in other seas we should expect to find here a number of stations either entirely positive or entirely negative, according to the climatic phase through which the country is passing, and between these stations other points which are not exposed to the direct influence of the water flowing from melting ice, and consequently where its effects are but feebly manifest or not at all.

And this is in fact the case.

From an identification of the *Gumbjorn skerries* of the older maps with the 'sunken land of Bus' it has been concluded that evidence of the alleged sinking of Greenland might be traced down to lat. 58° N.; but the objections raised by Major as to the truth of the identification show how baseless is this conjecture [1].

Robert Bell believes he has found traces of an active negative movement in *Hudson bay* still proceeding at a fairly rapid rate. He quotes in confirmation the sayings of the inhabitants, and lays particular emphasis on the rapid retreat of the strand at the mouths of the Nelson and Hayes rivers. The same movement is said to occur in East Maine, and indeed all along the coast from fort Churchill round the west of the great bay and the whole of James bay. Near the ancient fort Prince of Wales the subsidence is estimated at seven feet in the century. 'This retreat of the sea,' says Bell, 'may perhaps be ascribed to a general sinking of the sea-level with regard to the land, and in part to the silting up of some parts of Hudson bay, which interrupts the free course of the tides [2].'

It seems reasonable to suppose that the negative displacement in this region is the result of the same causes as act in the Baltic.

From *New Brunswick* to *Massachusetts* submerged forests and peat bogs occur in several localities, and might lead us to suppose that a positive dis-

Undersögelse, afgiv. 22 Marts, 1877. Særtryk af Tyllæg B til Rigsdagstidend. 1877–1878, Kjöbnhavn, 1877, p. 16; Meddelelser, 1881, II, pp. 40, 41 and 1883, IV, pp. 237–242. Here the author states that in Julianehaab and Frederikshaab mooring rings stand far below the level of high tide; this fact he regards as a sign of elevation, but adds that in the cryolite quarry of Ivigtuk three mooring rings were placed below high tide, because the rock above did not seem sufficiently secure.

[1] Major, Proc. Geogr. Soc. London, June 23, 1873, XVII, p. 321.

[2] R. Bell, Geological Survey of Canada, Report of Progress for 1878–1879, C, p. 24; op. cit., 1877–1878, C, p. 36 and CC, p. 29.

placement is at present in progress. The most detailed descriptions have been furnished by Dawson and Matthew; Cook, Gesner, and Guyot have also published similar accounts [1]. Very many of the observations refer to the coasts of the bay of Fundy, which, owing to its funnel-like form, compels the entering tidal wave to rise higher and higher until at the head of the bay the difference between low and high water amounts to more than sixty feet. As a fact opposed to the view that the land is at present sinking, Dawson himself points out that much of the flat country along the coast has of late years been dyked in and that the tide has thus become still more confined and perhaps even diverted [2]. But the evidence most adverse to all the arguments in support of the prevailing hypothesis has been furnished by H. Mitchell, who, while making measurements on these coasts, has succeeded in showing that there exist in this very region a great number of points fairly remote from one another, where no perceptible change in the relative position of land and sea has taken place for the last three centuries. Such fixed points are to be found from the gulf of St. Lawrence to Nova Scotia and as far as Massachusetts. The proof is furnished sometimes by the unaltered position of the salt marshes, which are still, as in 1609, covered twice a month by the spring tides; sometimes by isolated rocks such as the Isle Percée (Percé rock) on the peninsula of Gaspé, which is connected with the mainland at low tide, but separated at high tide by a passage through which a boat may pass, and it has maintained this state since 1603. We cannot therefore attach any importance to views of an opposite nature [3].

Many writers, and among them Lyell, have supposed that a general subsidence of the land is taking place in *South Carolina*. Tuomey has investigated the facts and has shown in a convincing manner that such a supposition is untenable. The coast is quite flat and marshy for long distances; by a subsidence of the land or a rise of the sea to the extent of only two feet the rice-fields would be destroyed far and wide. The presence of kitchen middens on James island in itself renders it improbable that any considerable oscillation can have occurred in recent times; yet none the less, the remains of forests which have been inundated by the sea, with the trunks of trees still projecting from the water, are certainly to be seen. In

[1] Dawson, Acadian Geology, 8vo, 1868, p. 28 et seq.; G. F. Matthew, Report on the Superficial Geology of Southern New Brunswick, Geological Survey of Canada, Report of Progress for 1877–1878, EE, p. 36 et seq.; G. H. Cook, On a Subsidence of the Land on the Sea Coast of New Jersey and Long Island, Am. Journ. Sci., 1857, 2nd Ser., XXIV, pp. 341–354; A. Gesner, On the Elevation and Depression of the Earth in North America, Quart. Journ. Geol. Soc., 1861, XVII, pp. 381–388, and in the Journal de l'Institut, Paris, 1862, p. 120.

[2] Dawson, Acadian Geology, p. 31.

[3] H. Mitchell, Notes concerning alleged Changes in the relative Elevation of Land and Sea; Rep. of the Superintendent of the U.S. Coast Survey for 1876–1877, 4to, Washington, 1880, Appendix 8, pp. 98–103.

some places these have been submerged by an inbreak of the sea, overwhelming a low-lying region which nature has dyked in by a bar; in others, however, the cause is different. When during an exceptionally high tide the sea is driven over a cypress swamp, the salt water soon kills all the growing plants, and this leads to a sinking of the whole ground together with the trees it supports. The water then permanently occupies the subsided region. There is yet another process, which is illustrated by Morris island. Here we find a line of dunes thirty to forty feet high; within them is a great marsh. As the dunes move inland they leave the roots of trees beneath exposed in great masses on the seaward side; the weight of the advancing dune causes the marsh to sink, together with the trees growing on it; outside the dune the trees are brought to light again below the level of high tide; frequently oysters may be seen attached to them [1].

We thus encounter in this region phenomena very similar to those already described on the coasts of the North sea.

The basis which supports the *Keys of Florida* as far as the Tortugas indicates a long-continued stability of the strand (II, p. 310). This stability is also revealed by the structure of the *Mississippi delta.*

The beds of Gnathodon shells to be met with at various heights above the Mississippi, which were regarded by Lyell as proof of a recent elevation of the land, are kitchen middens. It is true that at present Gnathodon is seldom to be observed alive above Choctaw point (one mile below Mobile), while fifty miles further up the valley extensive accumulations of shells containing Indian pottery lie beneath two feet of soil and the remains of an ancient forest [2].

The Mississippi, unlike many other rivers, does not open into a deep bay, forming so to speak a continuation of its valley, which must first be filled up before it can push out its delta into the open sea. Even at New Orleans the deposits of the Mississippi scarcely descend below −37 or −40 feet, and if, as in other cases, we are able to speak of the head of the delta, yet this cannot be placed higher up than the constriction between lake Pontchartrain and the Grand lake. It is only the inner 'bayous' or blind arms, such as Atchafalaja and Plaquemine, which assist in the formation of the inland parts of the delta, and the volume of water they contain is not more than about one-twelfth that of the river. All the rest of the water of the Mississippi, together with by far the greater part of its suspended sediment, is

[1] Tuomey, Report on the Geology of South Carolina, 4to, Columbia, 1848, pp. 190–200. O. Lieber subsequently thought that he recognized positive movement chiefly because oyster shells with ancient pottery occur as far as 30 miles up from the river mouths. These appear to me to be kitchen middens behind recently formed land; Lieber, Notes on certain Ancient and Present Changes along the Coast of South Carolina, Am. Journ. Sci., 1859, 2nd Ser., XXVIII, pp. 354–359.

[2] Humphreys and Abbot, Report upon the Physics and Hydraulics of the Mississippi River, reprinted with additions, 4to, Washington, 1876, p. 464.

carried out beyond the ancient coast-line, and not before this is passed does deposition begin to take place. Then the various branches of the river build up the long narrow mounds upon which they flow. From time to time, without any seismic disturbance, a mud-cone arises from the depths near the termination of those mounds which have advanced furthest into the sea. An opening is formed from which brackish water, liquid mud and combustible gases make their escape, sometimes gradually, sometimes in a sudden outburst. At high water the activity of these 'mud-lumps' increases, after some time the eruption comes to an end, but there remains behind a new fixed point which aids in the advance of the pass [1].

In addition to these singular eruptions, movements of an altogether different kind sometimes occur.

On April 13–14, 1876, as Forshey informs us, there occurred in the Passe à l'Outre a remarkable disturbance which rendered it necessary to abandon dredging operations in this branch of the river.

In a single night the whole neighbourhood had changed its aspect; a 'mud-lump,' or some similar alluvial mass, had arisen out of a depth of seven or eight feet of water; running obliquely across the channel of the river, it stood in some places as much as nine feet above the water, extending over an area of seventeen acres, which had previously been submerged. The movement, which resembled that of a glacier, was directed forwards, and continued through the whole of the summer; it was accompanied by elevation and subsidence of various amount and expressed itself in the form of furrows and folds, which spread over more than a thousand acres. The dredgers engaged in the pass found it impossible to maintain a passage over the ridge, and in August they abandoned the attempt. It was definitely ascertained that the movement was continuous and normal to the curve of the bar at the mouth of the pass [2].

This description suggests one of those gliding and folding movements which sometimes affect the upper mass of a delta and produce bending, folding, and shearing in its interior. The continuous, glacier-like movement, the production of folds on the surface, the magnitude of the area affected, the impossibility of checking it by human agency—these are indeed the characters of such a phenomenon.

Thus then, the great mass of mud is subject to changes of divers kinds, but, as at Aigues-Mortes and on the Po, the existing bars prove that no important displacement of the strand-line can have occurred for a long

[1] General Humphreys' letter to Sir C. Lyell, op. cit., p. 648; E. Hilgard, On the Geology of the Delta and the Mud-lumps of the Passes of the Mississippi, Am. Journ. Sci., 1871, 3rd Ser., I, pp. 357, 432.

[2] C. G. Forshey, Physics of the Lower Mississippi River; Proc. Am. Assoc. Adv. Sci., Twenty-sixth Meeting at Nashville, 1877, 8vo, Salem, 1878, p. 153 note. Similar glacier-like movements are mentioned by Hilgard on Petite Anse island; Geology of Lower Louisiana, Smiths. Contrib. to Knowledge, 1872, XXIII, No. 248, p. 18.

time past. An outer chain of bars, representing the existing line along which the river and the sea contend for mastery, runs in the east from the Chandeleur islands to some distance outside of fort St. Philip, and in the west from Timbalier island towards Atchafalaja bay. At the same time, inside this chain of bars there is an older inner bar which runs a little outside Mobile bay towards Cat island. If in the course of the last few centuries the strand-lines had been displaced to any considerable extent, then this older bar would either have been buried beneath the sediments or elevated above the existing bar. But it lies precisely at the same level as the formations of the present day.

Let us now return to the north and direct our attention to those traces of a displacement of the strand which have been preserved from remote times.

While all the statements made as to movements of the strand-line still in progress are more or less doubtful or incorrect, yet of negative movements which date from an earlier period, abundant proofs are to be met with, both around the North Atlantic and on the shores of the Arctic Ocean. Many investigators, among whom Middendorff may be especially mentioned, have observed that indications of elevation increase in number towards the north pole. But after the results we have obtained in the fjords of Norway we cannot accept without further examination every one of the numerous high-lying terraces observed in the Arctic regions as a definite proof of the presence of the sea at a higher level. Even the occurrence of small sea-shells in isolated examples is not indisputable evidence; many years ago the distinguished naturalist Steenstrup showed the necessity for caution in this matter, pointing out that the eider-duck brings up shell-fish from surprisingly great depths, and even specimens of *Rhynconella psittacea*, the shells of which it ejects from its crop on the top of the rocks [1].

The unusually exact observations made in the south-west of Greenland (II, p. 356) show clearly that the terraces extend to much more considerable heights than the shell beds. Unfortunately the accounts from the extreme north are not always satisfactory; attention has been too exclusively directed to the terraces; these have been taken offhand as so many shore-lines of the sea; it is seldom enough that we are in a position to discover with absolute certainty to what height the shell beds actually extend. There is besides the difficulty that in some places horizontal lines of the most striking appearance, and slopes looking as though they were entrenched, have no connexion with the recent terraces, but are produced by the horizontal stratification of the Palaeozoic limestone, as, for instance, in the case described by Sutherland at cape Felfoot (lat. 74° 31′ N., long. 88° 20′ W.)[2].

[1] Nordenskiöld also warns us against this source of error; Bihang k. svenska Vet., Akad. Handl., 1877, IV, No. 1, p. 19.

[2] P. C. Sutherland, Journal of a Voyage in Baffins Bay and Barrow Straits under the Command of Mr. William Penny, 8vo, 1852, I, pp. 286-288, and II, p. 284.

Some examples of terraces may now be enumerated, and particularly, but not exclusively, such as are distinguished by the presence of sea-shells.

On the east side of Greenland, Payer has encountered terraces at many places between lat. 75° 20′ and lat. 73° N. They occur in great numbers on the north-east of *Shannon island*, one above the other, reaching a height of several hundred feet; they reappear on the south of *Sabine island*, on the coast between *cape Broer Ruys* and *Mackenzie bay*[1].

On the north-west side of Greenland they are developed in an altogether extraordinary manner, and extend into the extreme north, as far indeed as man has yet penetrated, often accompanied to considerable heights by sea-shells. Captain Feilden states that he found some indications of this kind at almost every point which he visited in *Smith sound*, as well as north of the sound in *Grinnell land*, and on the opposite coast of Greenland. Up to lat. 82° 35′ N. marine shells were collected from the terraced land high above the existing shore. In *Discovery harbour*, Grinnell land (lat. 81° 45′ N.), where the *Discovery* wintered during 1875–6, beds with *Saxicava rugosa*, *Astarte borealis*, and other Arctic species lie a thousand feet above the existing sea-level. In *Polaris bay* (lat. 81° 40′ N.) driftwood and *Mya truncata* occur, according to Bessels, up to a height of 1,800 feet above the sea. Hayes mentions that in all the harbours and bays which he visited north of cape York, terraces were to be seen, especially in *Van Rensselaer harbour* (lat. 78° 40′ N.). In *port Foulke* (lat. 78° 20′ N.) he observed twenty-three terraces rising one above the other in a very regular series[2].

'I counted to-day,' says Kane, 'forty-one distinct ledges or shelves of terrace embraced between our water-line and the syenitic ridges through which *Mary river* forces itself. . . . Their breadth was either twelve, twenty-four, thirty-six, or some other multiple of twelve paces. This imposing series of ledges carried you in forty-one gigantic steps to an elevation of 480 feet. . . . They are more imposing than those of Wellington channel, . . . and reminded me of the parallel roads of Glen Roy. . . .[3]'

The indications in the south-west of Greenland have already been mentioned (II, p. 356).

In *Cornwall* and *Beechey islands* (lat. 74° 40′— 75 N.) in Barrow strait and *Wellington channel* Sutherland observed shells belonging to living species of Arctic marine mollusca a thousand feet above the sea, on the highest points of the land. The terraced form of the coast is par-

[1] J. Payer, Die österreichisch-ungarische Nordpol-Expedition in den Jahren 1872–1874, 8vo, 1876, pp. 471 and 561.

[2] H. W. Feilden, The Post-tertiary Beds of Grinnell-Land and North Greenland, Ann. Mag. Nat. Hist., 1877, 4th Ser., XX, pp. 483–489; also Heer, Quart. Journ. Geol. Soc., 1878, XXXIV, p. 66 et passim; Bessels, Bull. Soc. géogr. Paris, March, 1875, pp. 291–299; Hayes, Das offene Polar-Meer, 8vo, 1868, pp. 288, 344.

[3] E. K. Kane, Arctic Explorations, II, p. 81.

ticularly well seen, according to Armstrong, on the smaller of the *Princess Royal islands* (Investigator strait) between Baring island and Prince Albert land. In *Baring island* itself, on the summit of Coxcombe chain, M'Clure collected *Cyprina islandica* 500 feet above the sea; and in *port Kennedy*, at the northern end of the peninsula of Boothia, Dr. Walker, one of the companions of M'Clintock, found *Saxicava rugosa*, *Astarte borealis*, *Cyprina islandica* and other species at various heights, from 100 to 500 feet. At 150 feet lay the bones of a whale [1].

In conclusion we may mention that Klutschak, Schwatka's companion, on his journey from the north coast of Hudson bay to King William's land, found terraces at heights of thirty to forty feet, along the flat coast in *Simpson strait* [2]. We will now leave the Arctic archipelago and turn our attention to Hudson bay.

In the north part of *Hudson strait*, indeed along the whole coast between Nain and Resolution island (lat. 62° N.), Captain Ichabod Handy observed high-level terraces, as for example at Nain, where an ancient littoral formation occurs 300 feet above the sea, and in Resolution island, where a similar formation is found at 200 feet with three terraces. The terraces near *Smyth harbour* in the north-east part of Southampton island were seen long ago by Back, who was filled with astonishment at their regularity. The recent marine deposits with *Saxicava rugosa*, *Pecten islandicus*, *Rhynconella psittacea*, and other representatives of the existing fauna do not pass much beyond the existing outline of Hudson bay; R. Bell found them on Churchill river, 96 kilometers above the mouth, at a height of about 350 feet above the sea-level; in the basin of the Nelson river up to lat. 56° 31′ N. at a height of 200 feet; along the *Kenogami*, a tributary of the Albany, about 450 feet, and on the *Missinibi*, in the basin of the Orignal river (Moose river), about 300 feet above the sea. South-east of Hudson bay, on all the islands and coasts of *East Main*, traces of a relict strand are to be seen up to 300 feet, and Bell had no doubt that further inland they exist at an even greater height. Driftwood lies here thirty, indeed even forty and fifty feet above the sea, but disappears at greater heights under the action of the weather [3].

[1] P. C. Sutherland, On the Geology and Glacial Phenomena of the Coasts of Davis' Straits and Baffins Bay, Quart. Journ. Geol. Soc., 1853, IX, p. 300; Armstrong, Personal Narrative of the Discovery of the North-west Passage, 8vo, 1857, p. 267; Haughton, Geological Account of the Arctic Archipelago, drawn up from Specimens collected by Capt. M'Clintock, Geol. Soc. Dublin, Jan. 11, 1860, in Nat. Hist. Review, VII, 1860, p. 156; also M'Clintock, Journal of the Voyage of the *Fox*, appendix.

[2] H. W. Klutschak, Als Eskimo unter den Eskimos, 8vo, 1881, p. 113.

[3] A. S. Packard, jun., Observations on the Glacial Phenomena of Labrador and Maine, Mem. Boston Soc. Nat. Hist., 1867, I, p. 226; Back, On the North-Eastern Shore of Southampton Island, Journ. R. Geogr. Soc., 1837, VII, pp. 462-466; R. Bell, Report of Explorations on the Churchill and Nelson Rivers, &c., Geological Survey of Canada,

In Labrador, Hind observed terraces up to a height of 1,000 or 1,100 feet. Here, as in Norway, they are sometimes cut in the hard rock, as for example in Strawberry harbour, where they occur up to 500 feet according to Packard; in Domino harbour they are cut in quartzite, in other places in trap, and they appear to be true seter. Particularly well defined are the terraces on the two sides of Belle Isle strait. Chimmo describes the regular terraces in the harbour of Aillick. In Newfoundland Milne traced terraces up to 1,000 feet[1].

The recent marine beds which we have encountered in the extreme north, around Hudson bay and far away up to the valleys of the Albany and Moose river, finally reach Kingston at lake Ontario, and, characterized by all the signs of a transgressive marine formation, cover a not inconsiderable part of the country. These beds have been termed by Dana and many other American geologists the *Champlain series*, since they are particularly well developed around lake Champlain, south of Montreal; by Dawson and others they are spoken of as *post-Pliocene*.

These marine beds lie above the drift and are consequently more recent than the glacial period. Proceeding from New Brunswick towards the south, the series is seen overlying the boulder clay, and presents two subdivisions; the Leda clay at the base and above it the Saxicava sand. The Leda clay, according to Dawson, is of very variable thickness, attaining a maximum of 100 feet; in some cases it contains no other fossil than *Leda arctica*, and it closely resembles the deposits now accumulating in the gulf of St. Lawrence; it was probably formed at depths of 20 to 100 fathoms. The boundary of the Saxicava sand is apparently not always clearly defined.

There is no indication to show that the climate was more severe during the Champlain period than it is at present. It is true that, according to Dawson, the species of the existing Canadian flora which are found in the Leda clays of Ottawa are more especially those which are capable of enduring a fairly severe climate, but Arctic forms do not occur. On the other hand, we cannot fail to be surprised by the very frequent occurrence of twigs and leaves of *Populus balsamifera*, now rare in the neighbourhood of Ottawa; but these remains may have drifted. Remains of *Populus*

Report of Progress for 1878-1879, C, pp. 23, 28; Report on an Exploration in 1875 between James' Bay and Lakes Superior and Huron, op. cit., 1875-1876, p. 378; Report on an Exploration of the east coast of Hudson's Bay, 1877, op. cit., 1877-1878, C, p. 36, and CC, 12; also Trans. Roy. Soc. Canada, 1884, II, p. 241 et seq.

[1] Hind, Observations on the supposed Glacial Drift in the Labrador Peninsula, Quart. Journ. Geol. Soc., 1864, XX, pp. 122-130; A. S. Packard, jun., On the glacial Phenomena of Labrador and Maine, Mem. Boston Soc. Nat. Hist., 1867, I, pp. 223, 227; W. Chimmo, Visit to the North-East Coast of Labrador, Journ. Geogr. Soc., 1868, XXXVIII, p. 271; J. Milne, Notes on the Physical Features and Mineralogy of Newfoundland, Quart. Journ. Geol. Soc., 1874, XXX, p. 726.

balsamifera still frequently occur in very high latitudes among the drift-wood. The bison is mentioned by Lyell as occurring in these deposits[1].

The Leda clay also contains remains of the Greenland seal, and of the walrus; nodules of clay enclosing skeletons of the caplin (*Mallotus villosus*) and the lump-fish (*Cyclopterus lumpus*) are also found in it, and many foraminifera, all belonging to species still living in the gulf of St. Lawrence. On the other hand, the great whale, *Belluga Vermontana*, which was found in the Saxicava sand, appears to differ from all existing species.

With regard to the rich molluscan fauna of the Champlain stage Packard mentions the following facts:—

One or two species, *Fusus Labradorensis*, and perhaps *Bela robusta*, must be regarded as extinct; all the others are still living, and their distribution is at present determined by essentially the same conditions as existed during the Champlain period. Between the two regions of the Arctic marine fauna represented by Greenland and cape Cod there now exist two other well-defined marine faunas. The first of these, the *Syrtensian* or Labrador fauna, inhabits Hudson bay, Labrador and the north coast of Newfoundland. It follows, however, in streak-like extensions that branch of the cold counter-current which separates the Gulf stream from the continent, and forming isolated colonies on the sand-banks of the coast it penetrates some distance towards the south. It thus encroaches on the region of the southern or *Acadian* fauna, which depends in its advance towards the north on the distribution of the Gulf stream.

The molluscan fauna of the Leda clay and of the Saxicava sand shows that during their formation the Syrtensian fauna inhabited the St. Lawrence as far up as Quebec and Montreal, while east of the Saco river and at Portland this fauna, together with the few intermingled Arctic species, was replaced by the Acadian fauna.

From this Packard infers that at that time a branch of the cold counter-current flowed through the existing strait of Belle Isle and up the existing St. Lawrence towards lake Champlain, while the eastern region was subjected to the warming influence of the Gulf stream. Consequently a few of the Arctic members of the Syrtensian fauna, such as *Leda arctica*, *Pecten groenlandicus*, and others, extended further south than at present, but on the other hand we find as far north as Nantucket some species in these deposits, such for instance as *Venus mercenaria*, which are typical of the warm Virginian fauna[2].

[1] Dawson, Acadian Geology, p. 403; also, The Evidence of Fossil Plants as to the Climate of the post-Pliocene Period in Canada, Canadian Naturalist, 1866, 2nd Ser., III, pp. 69–76.

[2] A. S. Packard, jun., Glacial Phenomena of Labrador and Maine, p. 210 et seq.

The beds of Nantucket were described as early as 1849 by Desor and Cabot and since by Verrill and Scudder.

On Sankoty head, Nantucket island, the matted tubes of *Serpula dianthus* form a bed of serpulite intercalated between two shell-bearing beds; a similar growth of the same species of Serpula may still be seen between low-water and a depth of −8 fathoms in sheltered places along the south coast of New England and as far south as Carolina. The lower of the two shell-bearing beds just mentioned contains mollusca of a southern type, such as thick-shelled specimens of *Venus mercenaria*, mentioned above, then *Modiola hamata*, *Cumingia tellinoides*, *Arca subtransversa* and others, while in the higher bed above the serpulite lies a northern fauna with *Buccinum undatum*, *Astarte castanea*, *Cyclocardia boreale*, *Mya truncata*, &c. According to Verrill a large part of the sand-banks which here border the coast of America must be regarded, like the shell beds of Nantucket, not as deposits only recently formed by the sea, but as the remains of the denuded Champlain series [1].

The most important result, however, which follows from these investigations is *that the Gulf stream already existed at this period.*

The shelly sands extend up the St. Lawrence past Montreal to Kingston, while even much further towards the interior we still see terraced land, though without sea-shells. Dawson has given an excellent general description of this region and has determined the height of a great number of terraces. At three localities on the lower St. Lawrence, les Éboulements, Petite Mal bay and Murray bay (lat. 47° 40′ to 47° 30′ N.), the ancient strand-lines may be seen as follows:—at the first locality, one line occurs at a height of 274 meters, and below it six others; at the second, there are six lines, the highest at 228 meters; at the third, there are eight lines, the highest at 136·5 meters. On the isolated hill of mount Royal (Montreal, lat. 45° 30′ N.) a few principal lines are visible and between them many subordinate ones. The lowest important terrace, known as Sherbrooke-street terrace, lies at a height of 36·6 meters in the Leda clay; the next, Waterwork terrace, at a height of 67 meters, is excavated in the lower Silurian limestone, and I am not sure whether it should not be regarded as a seter. Three terraces occur at levels of 117·6, 134·1 and 143 meters; the latter of these is accompanied by a very clearly marked deposit containing pebbles and *Saxicava arctica* [2].

In the south of *New Brunswick*, Matthew has distinguished terraces up to a height of 105 meters, while according to Hind the highest strand-line

[1] Verrill, On the post-Pliocene Fossils of Sankoty Head, Nantucket Island, with a Note on the Geology by Scudder, Am. Journ. Sci. Arts, 1875, 3rd Ser., X, pp. 364–375; Scudder, Post-Pliocene fossils from Sankoty Head, Proc. Boston Soc. Nat. Hist., 1876, XVIII, pp. 182–185.

[2] Dawson, Acadian Geology, p. 39.

recorded in the bay of Fundy lies at 149 meters. On the coasts of *Maine* (lat. 45° to 43° N.) the same terraces appear at intervals; Shaler has definitely ascertained that their height above the sea decreases towards the south [1].

The fact that the strand-lines of this region decrease in height towards the south has frequently been emphasized by Dana; the following figures taken from Dana's lucid description may suffice to show this, for even if in many cases the upper part of the littoral formations has since disappeared, yet this will not destroy the correspondence.

On the lower St. Lawrence we found the considerable altitude of 274 meters, but shells are absent; in the bay of Fundy 149 meters; at Montreal, where shells occur, 143 meters. On the shores of *lake Champlain* (lat. 45° to 44° N.) Dana mentions terraces at a height of 120 meters, containing marine shells up to a height of 99 meters; at *point Shirley*, near Boston (lat. 42° 45′ N.), only at 22·8 meters to 30·4 meters; at Nantucket (lat. 41° 20′ N.) at 26 meters; finally on the south coasts of New England (up to about lat. 41° N.), they are only 40 to 50 feet (12·2 to 15·3 meters) above the sea-level [2].

Much still remains obscure, and no doubt the height of a deposit does not depend solely on the height of the sea-level, but on numerous other circumstances as well; yet we may record as a provisional result that at high latitudes in the east of North America recent shell beds occur at a great height, and that the post-glacial Champlain beds, which are probably their continuation, descend towards the sea-level as they approach the south, and especially between the fiftieth and fortieth parallels.

The terraces which occur towards the interior, in the north of the United States, are not all of the same kind; many are river terraces, others, like the Norwegian terraces, result from the damming up of a valley by ice. Davis has rightly illustrated the formation of these by lake Marjelen on the Aletsch glacier, and even supposes that the terraces which are visible 200 to 300 feet above the existing level of lake Superior owe their origin to comparatively small sheets of water which once lay between the shore and the front of the receding ice [3].

These phenomena need not detain us longer, and we will pass on to the most recent marine deposits of northern Europe.

[1] G. F. Matthew, Report on the Superficial Geology of Southern New Brunswick, Geological Survey of Canada, Report of Progress for 1877–1878, EE, p. 35; N. S. Shaler, Recent Changes of Level on the Coast of Maine with reference to their Origin, Mem. Boston Soc. Nat. Hist., 1875, II, pp. 322–341.

[2] Dana, Manual of Geology, 2nd ed., 1875, p. 550; also Depression of Southern New England during the melting of the great Glacier, Am. Journ. Sci., 1875, 3rd Ser., X, pp. 409, 436 et passim.

[3] W. M. Davis, On the Classification of Lake Basins; Proc. Boston Soc. Nat. Hist., 1882, XXI, p. 353.

2. *Eastern coasts of the North Atlantic.* James Geikie points out that neither the Faeröe, the Shetland, nor the Orkney islands show any trace of a displacement of the strand within the existing period; in the Faeröe islands caves occur which have been hollowed out in the basalt cliffs by the breakers, but they all lie at the level of the existing strand and are not found at greater heights [1].

Nevertheless, on the coasts of western Europe indications of a change of level are not wanting, but by far the greater part relate to submerged forests and peat bogs. I will only mention the much-discussed case of the coast of France.

The existence at the mouth of the Garonne of a continuous subsidence of the soil, proceeding with considerable rapidity, has been regarded as a definitely established fact. The following have been alleged as proofs: the submergence beneath the tide of large areas which had previously remained uncovered; the discovery of prehistoric sites beneath the level of high tide; finally, the progressive diminution of the island of Cordouan which lies to the west outside the mouth of the river, and the subsidence of this island together with the lighthouse which stands upon it. A critical study by Artigue shows that all these indications are deceptive. The tide at present covers a larger surface in the region of the estuary, because with the progress of deposition the depth of the river has diminished; and at the same time, owing to erosion, the opening by which the tide enters the estuary has been enlarged from 4·7 to 6·3 kilometers since 1785. Through this widened entrance a larger quantity of water passes at high tide, and in consequence a larger surface is submerged. The prehistoric settlements are certainly below high-tide level and are daily covered by the sea, but they lie on the outer border of the dunes. The land within the dunes lies equally low and shows similar traces of prehistoric occupation; here they are protected by the dune. The settlements outside the dune are therefore only an indication of the advance of the dune, *while the level of the mainland has remained unchanged.* The island of Cordouan has not sunk, otherwise the range of its light would have diminished, and this is not the case; its decrease in size is the result of marine erosion [2].

Passing from this example of a displacement supposed to be still progressing, let us again turn our attention to indications dating from an earlier period.

In *Iceland*, particularly in the south-west part of the island, a shell-bearing clay occurs, and in one place near Reykjavik, tuff, which also contains

[1] J. Geikie, On the Geology of the Faeröe Islands; Trans. Roy. Soc. Edinburgh, 1880–1881, XXXa, p. 263.

[2] H. Artigue, Étude sur l'estuaire de la Garonne et la partie du littoral comprise entre la Pointe de la Coubre et la Pointe de la Négade; Actes Soc. Linn. Bordeaux, 1877, 4e sér., I, pp. 287–307, pl.

marine shells. A strand-line above them at a height of 40 meters marks, according to Keilhack, the sea-level of the period; the molluscan fauna resembles that of Spitzbergen; the deposits rest on lava with a glaciated surface; they are correlated with the Champlain series of North America [1].

Of a different character are the shell-bearing beds of Húsavik in the north of the island (lat. 66° 10′ N.), which alternate with beds of tuff and lignite; they appear from Gardner's description to reach somewhat greater heights than those of Reykjavik, and their fauna is different (II, p. 132). Mörch and S. V. Wood believe that they are contemporaneous with the English Crag, particularly the red Crag; Gwyn Jeffreys, who regards them as more recent, points out that several species occur at Húsavik which belong to the existing fauna of North America, as for example, *Mesodesma deauratum*, *Natica heros*, and others. This fact is the more remarkable since the existing marine fauna of Greenland presents a European rather than an American character; possibly it furnishes an additional indication of the age of the Gulf stream [2].

The marine deposits of *Norway* are known in greatest detail in the Christiania fjord; the descriptions of Sars, Kjerulf, and others furnish us with the following facts.

Two different marine deposits occur; the strand of the older deposit was situated at a height of about 600 to 620 feet (188 to 194 meters), and that of the younger at a height of about 240 feet (75 meters).

The older fauna presents an Arctic character and is therefore generally described as glacial, although the deposits are more recent than the great ice sheet. *Mya truncata*, *Saxicava rugosa*, *Buccinum groenlandicum*, *Leda* (*Yoldia*) *arctica*, the last three with very thick shells, are among the most characteristic species. In the fjord itself near Dröback great quantities of dead specimens of *Oculina prolifera* occur between −80 or −70 fathoms and −8 or −7 fathoms, although at the present day this species does not live above −100 fathoms, and extends down to −300 fathoms. On the little island of Barholmen the clay with fragments of this coral reaches a height of +30 feet. These are the deposits of the lower zones belonging to the time of the older fauna; the negative movement has produced a diminution in the depth at which they occur, or has even left them exposed above the strand-line. The older deposits also contain the 'marleker,' i. e. flat nodules of marl, which, as Sars has pointed out, contain an Arctic molluscan fauna, and in which Collett has discovered the remains of a large number of Arctic and North Atlantic fishes, such as *Gadus morrhua*, *Mallotus villosus*, *Clupea harengus*, and others. These marleker apparently re-

[1] H. Keilhack, Ueber postglaciale Meeresablagerungen in Island; Zeitschr. deutsch. geol. Ges., 1884, XXXVI, pp. 145–160.

[2] J. Gwyn Jeffreys in J. St. Gardner, The Tertiary Basaltic Formation in Iceland; Quart. Journ. Geol. Soc., 1885, XLI, table to p. 96.

semble in every particular the nodules containing fish found in the Leda clay of Canada, which in other respects also presents the greatest similarity with the deposits occurring in Norway.

The more recent fauna is distinguished by the waning of Arctic characters; *Leda arctica* and *Siphonodentalium vitreum* have disappeared; *Pecten islandicus* is rarer, the shells of *Mya truncata* and *Saxicava rugosa* have become thinner, and the place of *Buccinum groenlandicum* is taken by *B. undatum*. Correspondingly such species as *Cardium edule*, *Littorina littorea*, and *Mytilus edulis* now begin to preponderate. Two immigrants from the Mediterranean even make their appearance, *Tapes decussata* and *Pholas candida*, both inhabitants of shallow water, which have not succeeded in maintaining an existence in Norway, and are now foreign to its seas[1].

Even as far as Trondhjem shell-beds with Arctic mollusca attain a height of 380 feet (119 meters; II, p. 350); but further north all traces of marine mollusca at high levels have disappeared; as already observed, I have not seen them in Tromsö stift, and Pettersen regards certain shell-bearing deposits, which here reach a height of 53 meters, as possibly interglacial (II, p. 354). On the other hand, the more recent stage lying at a lower level is clearly visible at several places on the shore up to and beyond lat. 70° N.

Many circumstances tend to confirm the view held by Pettersen and others, that the absence of the higher and older horizons is to be ascribed solely to the more prolonged glaciation of the north. Much caution is therefore necessary in all deductions which relate to the former presence of the sea over a part of Norway, first, because many of the high-level strand-marks have not been produced by the sea, but by glacial lakes; secondly, because observations in Greenland have shown that marine mollusca are absent in the vicinity of a glacier owing to the great quantity of fresh water it discharges; thirdly, because marine deposits could only be permanently formed when the slopes were free from ice, or so long as an interglacial episode existed.

Otto Torell, in his masterly classification of the more recent formations in Sweden, published in 1876, has also distinguished two marine deposits of very different age. The older of these consists of sand and clay with *Leda (Yoldia) arctica*; it is more recent than the great glaciation, and includes the shell-beds of Uddevallo, in which the Arctic characters are not so striking. It was not until later, after the formation of the terraces,

[1] M. Sars, Om de i Norge forekommende fossile Dyrelevninger fra Quartärperiod, Universit. Programm for I. Halvaar, 1864, 4to, Christiania, 1865; Kjerulf, Die Geologie des südlichen und mittleren Norwegen, pp. 1–7; R. Collett, De i Norge hidtil fundne fossile Fiske fra de glaciale og postglaciale Afleyringer, Nyt Mag. Naturvid., 1877, XXIII, 3. Häfte, p. 12.

according to Torell, that the second marine deposit was formed; this is assigned to the recent period and contains Mytilus, Tellina, and the existing fauna of the Baltic sea; it is the post-glacial stage of Norwegian geologists[1]. Even as far north as south Ångerman land, Gumaelius mentions *Mytilus edulis* and *Tellina baltica* at a height of 250 feet (77 meters); but in Finland Jernström did not succeed in finding the shell-bearing beds at a greater height than 60 feet; in Oesel, Franz Schmidt records them as occurring at between 30 and 60 feet above the sea, with a coastal wall in the gulf of Finland at a height of 100 feet (31·3 meters); and this trustworthy observer adds that they do not extend into the region of lakes Ladoga and Onega, although Arctic shell-beds were encountered by Murchison at Ust-Waga on the Dwina near the confluence of the Waga[2].

More to the south also, in *Germany*, these marine deposits attain but an inconsiderable height; Jentzsch has found *Leda arctica* in the Frische Haff in west Prussia, and has described marine beds near Marienwerder: Berendt mentions a bed near Collberg containing *Cyprina islandica* and North sea mollusca; in Schleswig-Holstein a marl occurs with *Cyprina islandica* in addition to Mytilus and Tellina. Nowhere, however, judging from the observations so far made, do these marine beds extend very far from the coast into the interior[3].

Great Britain has furnished a large number of observations relating to similar beds; I will confine myself to the comprehensive account given by Archibald Geikie. According to this observer Arctic marine mollusca are known in Scotland up to a height of 524 feet (161 meters); other shell-beds with a more or less pronounced Arctic character occur in many places at a less elevation, as on the Clyde for example, where the strand is supposed to have stood at a height of 100 feet (30·5 meters). Further south patches of shell-bearing sand have been found in a few localities at much more considerable heights, e.g. near Macclesfield in Cheshire at 1,200 feet (365 meters), and on the summit of Moel Tryfaen at 1,350 feet (411 meters; according to Ramsay about 1,170 feet = 357 meters). The

[1] O. Torell, Sur les traces les plus anciennes de l'existence de l'homme en Suède; Compte-rendu du Congrès archéol. de Stockholm, 8vo, 1876, pp. 2–4.

[2] O. Gumaelius, Snäckbankar i Ångermanland, Geol. Fören. Stockh. Forh., 1874, I, p. 233; Jernström, Om Finland's postglaciale Skalgrusbäddar, op. cit., 1876, III, pp. 133–140; F. Schmidt, Einige Mittheilungen über die gegenwärtige Kenntniss der glacialen und postglacialen Bildungen, etc., Zeitschr. deutsch. geol. Ges., 1884, XXXVI, pp. 248–273.

[3] e.g. A. Jentzsch, Die Lagerung der diluvialen Nordseefauna bei Marienwerder, Jahrb. k. preuss. geol. Landesanst., 1881, Berlin, 1882, pp. 546–570; Berendt, Zeitschr. deutsch. geol. Ges., 1884, XVI, p. 188; Jentzsch, op. cit., 1887, XXXIX, p. 492 et passim. Dames, Die Glacialbildungen der norddeutschen Tiefebene, Samml. gemeinverst. wiss. Vorträge, 1886, Heft 479, contains a list of more recent works on this subject.

latter locality has been described by Ramsay; the shelly sand lies partly concealed beneath a moraine. Geikie does not believe that the sea actually reached these heights; he considers that the sands were carried upwards by the ice. The whole of the 'Bridlington Crag' in Yorkshire, which contains Arctic mollusca, is said to be merely an erratic included in the boulder clay. In addition to these isolated patches at great heights, shell-beds also occur in England at lower levels, down to the numerous 'raised beaches' which border the existing coasts[1].

The remarkable conditions under which these beds sometimes occur have already been mentioned in treating of the coast of Sangatte near Calais (II, p. 416).

If we disregard the high-lying patches in Cheshire and Wales, admitted to be open to question, we shall find that Arctic mollusca occur in Scotland and in the Christiania fjord at closely corresponding levels. In Scotland they extend in fact to a height of 161 meters, and in Norway to 520 Norwegian feet (163 meters); a sea-level of 188 to 194 meters is deduced from the latter by considerations based on the depth at which similar mollusca live at the present day. But it does not appear as though the level descends in the direction of the Baltic provinces. The beds of Finland and the Baltic provinces no longer present the strictly Arctic characters of the higher levels, but resemble the lower stages of Scandinavia, i.e. those containing the existing fauna, or in other words, it is not that the height of the deposits decreases towards the east, but the older and higher beds disappear, while the lower are continued at a more or less constant level. How far the Arctic marine deposits lying at a great height have been subsequently destroyed, or to what extent deposition has been prevented by a long-continued glaciation of the country, must be left to further investigation. In any case there is no doubt that the lower-lying and more recent beds may be recognized on the coasts of Britain, as well as on those of Belgium and France. They indicate a widely extended strand at this level at a time much more recent than the glacial epoch. Even when the sea-level stood at 75 meters the Christiania fjord harboured, as we have seen, at least two Mediterranean immigrants, a fact suggestive of a climate milder than that of the present day, and to this period we must refer the light-coloured shelly sands of Bodö and Tromsö.

The question as to whether the height of these post-glacial marine deposits decreases towards the south is thus, like so many other questions, not so easily answered in Europe as in the United States. Nevertheless I believe that this decrease also occurred in Europe. In the high latitudes north of

[1] A. Geikie, Textbook of Geology, 2nd ed., 8vo, London, 1885, pp. 897–904; A. C. Ramsay, The Physical Geology and Geography of Great Britain, 5th ed., 1878, p. 413. Arctic shells are also said to occur on the Wicklow hills in Ireland at a height of 1,300 feet.

Europe traces of the sea are found at considerable heights, as will be shown directly. In south Norway and in Scotland, beds with Arctic shells lie at a height of 163 and 161 meters. More recent deposits, however, in which the Arctic character is less distinctly marked, possess a much wider distribution.

It must not be forgotten that the appearance of northern immigrants in the Mediterranean probably marks the period of severest cold. This period, however, is considerably anterior to the Leda clays and the equivalents of the Champlain beds; and these, although they contain Arctic mollusca, are certainly much more recent in Norway than the period of maximum glaciation. For this reason their chronological equivalents in the shell-beds of the Mediterranean probably lie at a lower level than the horizon in which most of the northern immigrants occur. It is also very probable that at the time of their deposition a larger area was covered with inland ice in the Arctic region than at the present day, and that consequently the high-lying shell-beds of this region are more recent than the Leda clays of Norway.

But let us leave these conjectures and again turn to the north.

3. *The north of Eurasia and the west coast of the north Pacific Ocean.* The terraces of Arctic America and of Greenland are repeated in *Spitzbergen*. A remarkable fact may be mentioned here. Nordenskiöld and Drasche observed the shells of *Mytilus edulis* on this island in great quantity at a trifling height above the strand; they had preserved their colour and ligament. This species, according to existing accounts, does not appear to live at present in such high latitudes. The remains are evidently quite recent, and the suggestion offered by some investigators, that they flourished during the warmer climate of an interglacial period, which affected the extreme north, does not suffice to explain them [1].

The Austria sound, *Franz Joseph's land*, is surrounded by shell-bearing detritus in terraces which, according to J. Payer's expression, look like hypsometric curves [2].

Middendorff has encountered similar terracing up to a height of 200 feet and over on Wadsö in the Varanger fjord, on the peninsula of Ribátschij and the island of Kildin on the *Murman* coast. Although no marine shells are mentioned from these localities, yet the existence of a transgression is scarcely open to doubt, since Murchison, as we have mentioned above, found shell-bearing beds near the confluence of the Waga with the Dwina near Ust-Waga; the sea has certainly covered the lower part of the existing valley of the Dwina since the glacial epoch [3].

[1] O. Heer, Die Miocene-Flora und Fauna Spitzbergens, mit einem Anhang über die diluvialen Ablagerungen Spitzbergens; K. svenska Vet.-Akad. Handl., 1870, VIII, No. 7, p. 80 et seq.

[2] J. Payer, Die österreichisch-ungarische Nordpol-Expedition, 8vo, 1876, p. 272.

[3] A. von Middendorff, Anékiew, eine Insel im Eismeere, in der Gegend von Kola; Bull. Acad. Imp. Sci. St.-Pétersb., 1860, II, pp. 153–158. It is probable from the

In *Nova Zembla*, Wilczek and Höfer observed terraced land with marine shells up to a height of 300 feet (95 meters), and Nordenskiöld found, in addition to marine shells which had been carried by birds, subfossil mollusca, particularly an Arca, in the bay of Rogatscheff, five kilometers from the existing shore at a height of 100 feet. While the negative movement is revealed in this manner on the great double island, the deposits containing mollusca of the glacial sea enter the lower part of the *Petchora* region, as we learn from the observations of Keyserling which have been confirmed by Karpinsky; they appear on the lower Ob, and the investigations of F. Schmidt, Lopatin, and Nordenskiöld show that on the lower *Yenisei* also and to beyond Dudino (lat. 69° 20′ N., about) the same marine deposits occur. They form the subsoil of the tundra, and Middendorff traced the marine shells, particularly *Mya truncata*, above the river Taimyr up to a height of 200 feet [1].

In *Taimyr land*, however, in addition to the shell-bearing beds, we also see great quantities of tree-trunks arranged at definite intervals in long horizontal rows. These are the so-called *Noah-wood*. 'A closer examination,' says Middendorff, 'would probably show, even at the present day, that the Noah-wood is not distributed irregularly over the tundra, but lies in regular strand-lines which descend in approximate parallelism one behind the other to the sea, each single strand-line preserving for the whole of its course a fairly uniform height above the surface of the sea.' At the mouths of the *Lena* and the *Kolyma* and in many other districts of these Siberian coasts, the Noah-wood is mentioned at various heights above the sea. The question as to the origin of these beds of wood, however, is by no means solved; Bunge and Toll have shown that the 'wood mountains' of the New Siberian islands belong to those plant-bearing Tertiary beds which present so astonishing an extension in high latitudes [2].

description that Åsar exist on Rybátschij; Murchison, Verneuil, and Keyserling, Russia and the Ural Mountains, 4to, 1845, I, pp. 327–332.

[1] H. Höfer, Graf Wilczek's Nordpolfahrt im Jahre 1872, Peterm. Mitth., 1874, p. 302; Wissenschaftliche Resultate der zur Aufsuchung eines angekündigten Mammuth Cadavers von der K. Akademie an den unteren Jenissei ausgesandten Expedition, Mém. Acad. Imp. Sci. St.-Pétersb., 1872, XVIII, No. I, pp. 17 and 48; A. E. Nordenskiöld, Redogörelse for en Expedition till Mynningen af Jenissej och Sibirien, Bihang k. svenska Vet.-Akad. Handl., 1877, IV, No. 4, p. 69 et seq.; A. T. von Middendorff's Reise in den äussersten Norden und Osten Sibiriens, I, p. 206; IV, p. 261 et seq. Seebohm mentions marine shells, 'perhaps' even 500 feet above the Yenisei; Proc. Geogr. Soc. London, 1878, XXII, p. 112.

[2] Bunge, Account in Peterm. Mitth., 1887, XXXIII, p. 255. Lindeman, for instance, states that between the Lena and Bering strait traces of weathered driftwood occur in some places fifty versts from the sea, 'whither the waves have long been unable to penetrate'; Peterm. Mitth., 1879, XXV, p. 172. Similar distances on the tundra are given by Wrangel in his Reise längs der Nordküste von Sibirien und auf dem Eismeere in den Jahren 1820–1824, 8vo, Berlin, 1839, p. 256.

From the accounts describing the occurrence of marine deposits on the lower course of the Lena, the Indigyrka, and the Kolyma, it appears to be beyond dispute that the lower course of all the great Siberian rivers was covered by the sea to a greater or less extent, and that at a time more recent than the glacial epoch.

Recent shell-beds, such as are known on the Aleutian islands, are apparently not absent in *Kamchatka*. On the slopes of the *Kurile* islands terraces are known; in particular near Furubets in Iturup, the largest of the Kuriles (lat. 44° 30′ N. to 45° 30′ N., about), where Milne describes two stages, one at a height of 400 to 500 feet, the other at 130 feet. Elsewhere in the Kuriles only the second of these has been observed. In the neighbouring locality of Nemoro in the island of Yezo the same observer mentions a stage at a height of thirty to forty feet[1].

In this region the terracing of the shores generally appears to be very striking. Pumpelly mentions recent marine terraces as occurring at various places from Yezo on the coast of *Japan*, to as far as Kiu-siu and the border of the great deltaic plain of China near Tshi-fu; these stages are especially well marked in the south of Yezo, and they also occur near Yokohama. Volcano bay and the north coast of Tshugar strait are surrounded by terraces, according to Bickmore. North-east of Sendai in the bay of Kemana-ëura, Rein observed on a limestone cliff a horizontal band almost a meter in breadth, perforated all over with holes in which hundreds of shells of boring molluscs may still be seen; from this he inferred that a recent elevation of the land had taken place to the extent of nearly two meters. Naumann has collected many facts bearing on this subject, chiefly in the neighbourhood of Tokio and the Japanese archipelago in general, and these also indicate displacement in the negative direction[2].

Further south, indications of negative movement do not absolutely disappear, but they become less and less marked[3].

[1] J. Milne, The Volcanoes of Japan; Trans. Seis. Soc. Japan, Yokohama, 1886, IX, pt. II, pp. 151, 164.

[2] R. Pumpelly, Geological Researches in China, &c., Smiths. Contrib. to Knowledge, 1866, in particular p. 108; Godfrey, Geology of Japan, Quart. Journ. Geol. Soc., 1878, XXXIV, p. 544; A. Bickmore, Some more recent Changes in China and Japan, Am. Journ. Sci., 1868, 2nd Ser., XLV, p. 217 (at Tshi-fu, according to Bickmore, only a long 'sand-spit' with two older strand-lines a few feet above the sea); J. J. Rein, Naturwissenschaftliche Reisestudien in Japan, Mitth. deutsch. Ges. Natur- und Völkerkunde Ostasiens, 1875, 7. Heft, p. 29; E. Naumann, Ebene von Yedo, Peterm. Mitth., 1879, XXV, p. 126; G. Davidson, Abrasions of the Coast of Japan, Proc. Calif. Acad. Sci., 1875, VI, p. 28; this author mentions a terrace at a height of about 100 feet on the island of Oö (lat. 32° 25′ N.).

[3] It was the mode of formation of the great plain which in 1874 led F. von Richthofen to the conclusion that from the north down to the Tshu-san islands negative movement is taking place; in the south, on the other hand, positive movement; Zeitschr. deutsch. geol. Ges., 1874, XXVI, pp. 957–960.

4. *The eastern coasts of the North Pacific Ocean.* When Kotzebue was detained on the west coast of America (in lat. 66° 15′ N.) by a violent storm on August 8, 1816, his companions Escholtz and Chamisso found that the hills near the shore consisted of ice covered by only a thin layer of earth; that this was ancient ice was shown by the number of mammoth remains revealed by summer thaws. This fossil ice possesses so great an extension that Chamisso did not hesitate to describe it as a geological formation [1]. Kotzebue called the place Escholtz bay; the fact has been subsequently confirmed by Beechey, Seemann, and other explorers; I follow here the latest description by Dall.

Extremely ancient ice, assuming the characters of an independent rock, extends with interruptions northwards to point Barrow, eastwards to Return reef (where the ice-bed begins about six feet above the sea), southwards to Icy cape, and in isolated patches as far as Kotzebue bay. It is not frozen ground but actual ice, not bluish-green like glacier ice, but dirty, often of a stratified appearance and sometimes yellowish, like frozen bog-water. Dall has examined it most closely at Elephant point near Chamisso island. Here it is accompanied by thin clayey beds with Sphagnum, shells of Pisidium and Valvata; in some spots very evil-smelling patches occur in the clay as though from putrefaction, precisely as in the neighbourhood of the mammoth and rhinoceros remains on the Siberian rivers; numerous bones of mammoths and ruminants are also found in this locality. We have here indeed a ridge of solid ice rising several hundred feet above the adjacent sea; it is higher than all the surrounding land and dates from a period older than the mammoth. The surface of the ice ascends in steps. The first cliff or ice-wall is about thirty feet high, counting in a superficial layer of earth two or three feet in thickness, which forms the summit; further inland rises a second ice-wall; Dall was able to trace it for a distance of four kilometers, and estimated the height of the summit above the sea at eighty feet. From here onwards the ridge gradually increases in height and assumes a rounded form; it consists entirely of ice and is nowhere bounded by higher ground. From the character of the beds containing Sphagnum, Dall concluded that the ice mass is not subject to any glacier-like movement. The overlying layer of clay attains a thickness of forty feet, contains bones of elephants, horses and buffalos, but only occurs up to a certain height, and apparently does not reach the summit of the ice mountain [2].

[1] O. von Kotzebue, Entdeckungsreise in die Südsee und nach der Beringstrasse, 4to, 1821, I, p. 146, III, p. 170.

[2] W. H. Dall, Notes on Alaska and the vicinity of Bering Strait, Am. Journ. Sci., 1881, XXI, pp. 104–111; Alaska-Forschungen im Sommer 1880, Peterm. Mitth., 1881, p. 46; A. Penck, Die Eismassen der Escholtz-Bai, Deutsche geogr. Blätt., Bremen, 1881, IV, pp. 174–189.

Similar masses of ice have since been observed by Bunge and Toll on the islands of New Siberia.

Middendorff was convinced that a general elevation, not only of Siberia, but also of north-west America and the Arctic regions generally, had taken place, but was deterred from drawing general conclusions by Pingel's observations on Greenland. This observer also mentions that in *Norton sound*, Sagoskin found masses of Noah-wood on the summit of the island of Saint Michael [1].

Dall too found trunks of trees in an advanced stage of decay arranged in long lines, far above the highest level of the tides, over the whole distance between Norton bay and Kotzebue sound; he regarded them as proof of an elevation of the land which extends in his opinion from long. 150° W. through the whole of the peninsula of *Aliaska*. Terraces are absent in the region of the Yukon and on the borders of the continent in the neighbourhood of Aliaska, and Dall connects this circumstance with the absence of indications of a general glaciation in this region [2].

In addition Dall found barnacles, at a height of at least fifteen feet, attached to the vesicular basalt of the island of Saint Michael mentioned above, and Grewingk long ago collected data showing the originally higher level of the strand in Aliaska, the Aleutian and the Pribyloff islands. When Grewingk wrote (1850) the recent marine deposits, which furnish the most direct evidence of these movements, were assigned to the latest period of the Tertiary aera, while the elephant-bearing beds visible in so many places, including those of Kotzebue sound, were regarded as diluvial. But even at that time, as we have mentioned above, Grewingk pointed out the striking similarity between the mollusca in these supposed marine Tertiary formations, and those of Beauport near Quebec on the St. Lawrence; the beds are in fact the representatives of the Champlain stage of Canada [3].

They have been found by Wossnessenski, Postels, Beechey, and others in various localities, as for instance on the island of St. Paul in the Pribyloff group (lat. 57° N.); in nearly the same latitude on cape Tonki, in the bay of Igatskoj, the east side of the island of Kadjak, i. e. on the north-east of the peninsula of Aliaska; the shells lie in volcanic tuff, forming a little cliff

[1] Middendorff, Reise in den äussersten Norden und Osten Sibiriens, II, p. 262 note. The description given by Cook of *Denbigh* peninsula in Norton sound has sometimes been cited as indicating elevation of the land, but it may also refer to the formation of land by silting up; A Voyage to the Pacific Ocean, 1784, II, p. 485. The reference to a find made by Lamanon in *Port des Français* (lat. 58° 37′ N.) of large *fossil* shells different from those living on the strand rests on an error; Voyage de la Pérouse autour du monde, publ. par Milet-Mureau, 4to, 1797, II, p. 189.

[2] W. H. Dall, Alaska and its Resources, pp. 462, 465.

[3] C. Grewingk, Beitrag zur Kenntniss der orographischen und geognostischen Beschaffenheit der Nordwestküste Amerikas, 8vo, 1850 (from the Verh. russ.-k. min. Ges. St. Petersb., 1848-1849), p. 249.

one and a half fathoms high. West of Kadjak they appear on the east coast of Aliaska; but they seem to attain their greatest development near the extremity of the peninsula in Morshovsky bay, Moller bay, Pavlov bay, and on the island of Unga (lat. 56° to 55° N.). In Morshovsky bay (Walrus bay) in particular a horizontal bed of these shells lies fifty toises above the sea-level, and above it follow horizontal beds of sand and clay with a thickness of another fifty toises.

In *Unalashka* they lie at the north-west foot of the volcano Makutshkin, and on the north side of the island of *Atka* (about lat. 52° 30′ N.) shells of the same species occur thirty feet above the sea in beds of hardened clay and friable sandstone [1].

For many centuries, however, no marked displacement of the strand-line has occurred on the Aleutian islands; this is proved by Dall's investigations of the numerous and extensive kitchen middens which take us back to a stage of human existence far anterior to that of the existing Innuit [2].

Towards the south the indications of a higher sea-level become less frequent, but are not altogether absent. At *fort Simson* (lat. 54° 34′ N.) an ill-defined terrace of loose material lies on the coast at a height of 100 feet; south of this point near Metla Katla it becomes clearly marked, at a height of ninety-five feet above high tide. Dawson, to whom we owe most of the observations on these regions, records that in Skidegate inlet (lat. 53° 10′ N.), which separates the two largest islands of the *Queen Charlotte* group, he found sandy clay with Leda, Cardium, and Balanus resting on glacial deposits.

In the *strait of Georgia* terraces are known at a height of 100 and 200 feet. Near Nanaimo in Vancouver, shell-beds with *Saxicava rugosa*, Mya, and Leda rest at a height of 170 feet on ancient glacial formations. Similar shell-beds were found some time ago near Victoria by Blake, twenty feet above high tide [3].

[1] Grewingk, tom. cit., in particular p. 274 et seq., also p. 54 et passim. I feel some doubt as to the specimen from the Pribyloff islands figured by Pinart owing to its state of preservation; Pinart, Voyages à la côte nord-ouest de l'Amérique, 4to, 1875, I, p. 35, pl. A, fig. 7. Lutké (Voyage autour du monde sur la corvette la *Sémiavine*, III, edited by A. Postels, 8vo, Paris, 1836, p. 27) describes the horizontal beds with shells in Alaska; the palaeontological determinations were made later according to Wossnessenski's collections.

[2] Dall, Tribes of the Extreme North-West; Contributions to North American Ethnology, I, 1877 (Powell, Geogr. and Geol. Survey of the Rocky Mountain Region), p. 41 et seq.

[3] G. M. Dawson, On the Superficial Geology of British Columbia, Quart. Journ. Geol. Soc., 1878, XXXIV, pp. 97, 99; and Additional Observations, op. cit., XXXVII, 1881, p. 278. Similar data in H. Bauermann, On the Geology of the South-Eastern Part of Vancouver Island, Quart. Journ. Geol. Soc., 1860, XVI, p. 202; Dawson, Report on the Queen Charlotte Islands, Geological Survey of Canada, Report of Progress for 1878–1879, p. 110 B. I have not mentioned the shell-bed at a height of fifteen feet (p. 114 B et seq.), because it recalls kitchen middens; Blake, U. S. Coast Survey for 1867, p. 281;

As compared with the accounts we possess of relict shore-lines in some regions, those from these coasts are scanty enough; all the more striking, therefore, are the full and precise descriptions which relate to the terraces so characteristic of all the valleys of the interior. These river terraces are so sharply defined and extend to such great heights that no traveller has omitted to mention them. In Puget sound, terraces are recorded up to a height of 1,600 feet; they extend across the low watershed into the Cowlitz valley; but as to the maximum height at which these terraces afford evidence of the action of the sea, we have no knowledge [1].

An admirable description of the inland terraces on the Saskatchewan, the Athabasca, the Vermilion, the Upper Columbia, and the Fraser river has been furnished by Hector; he recalls the fact that Logan had previously observed terraces up to a height of 331 feet (100 meters) above lake Superior, and from this he concluded that a submergence had affected the whole continent up to a height of 3,000 feet above the existing sea [2].

Dawson observed a terrace of worn pebbles at a height of 5,270 feet (1,606 meters) on the northern slope of the mountain *Il-ga-chuz* west of the Fraser river, and was disposed to admit a submergence to the extent of 4,000 or 5,000 feet. His latest accounts, however, seem to indicate that he is now inclined to explain the inland terraces in connexion with extensive lakes and fluviatile action. They have nowhere afforded remains of marine shells [3].

These fluviatile terraces belong indeed to phenomena of another order, and do not indicate a wholesale submergence of the land. In Europe there are numerous examples of river terraces far removed from the region in which oscillations of the strand-line occur. River terraces also occur on

Topographical and Geological Features of the North-west Coast of America, Am. Journ. Sci., 1868, 2nd Ser., XLIV, p. 243; Grant, Journ. R. Geogr. Soc., 1857, XXVII, p. 285.

[1] J. S. Newberry, Surface Geology of the Country bordering the N. Pacific Railroad; Am. Journ. Sci., 1885, 3rd Ser., XXX, p. 344.

[2] J. Hector, On the Geology of the Country between Lake Superior and the Pacific Ocean, Quart. Journ. Geol. Soc., 1861, XVII, pp. 388–445. Hind describes those on the south Saskatchewan; op. cit., 1864, XX, pp. 122–130. A vivid description of the terraces on the tributaries of the Fraser was given by Milton and Cheedle, The North-West Passage by Land, 8vo, 3rd ed., 1865, p. 338 and pl.; also Begbie, Proc. R. Geogr. Soc., Feb. 27, 1871. As early as 1832 Capt. Back observed 10–11 terraces on the Great Slave lake, and on studying the outflow of the lake in the Great Fish river he concluded that the water level had sunk. This river, like Nelson river by which the outflow of lake Winnipeg takes place, is interrupted by rocky cataracts; Back, An Account of the Route and Appearances of the Country from Great Slave Lake in the Polar Sea, Journ. R. Geogr. Soc., 1836, VI, p. 5.

[3] G. M. Dawson, Quart. Journ. Geol. Soc., 1878, p. 21, and 1881, p. 283. An illustration and numerous measurements referring to river terraces in Geological Survey of Canada, Report of Progress for 1875–1876, p. 290, and 1877–1878, p. 168 B et seq.; an illustration of the terrace of the Il-ga-chuz, op. cit., 1876–1877, pl. ii.

the lower course of the Columbia and in all the river valleys as far down as the Sacramento, but we need not give further consideration to them here.

The submerged forests near the mouth of the Columbia river are explained by Dana as the result of local landslips [1]. Near the mouths of the *Coquille* and *Umpquah rivers* and in *Koos bay* (lat. 44°–43° N.) the coast is described by Goodyear as a table-land, 200 to 800 feet in height, with traces of oscillations; two valleys are sunk into this table-land; they are several miles in length and the waves advance up them far into the interior [2].

With regard to the terraces along the coast of *California*, much uncertainty prevails. North of fort Ross (about lat. 38°–40° N.) a long terrace occurs which, according to Becker, presents the characters of an ancient beach; borings of Pholas were observed here, in one place at a height of about 100 feet (30·8 meters), in another at about twice that height [3].

In the bay of *San Francisco* and northwards on the shores of San Pablo bay (lat. 38° 10′–17° 30′ N.), traces of a negative movement of the strand-line are clearly visible. On the north shore of Lobos creek, a little river which descends from Mountain lake to the sea, Blake observed shells of existing species and pebbles at a height of 80 to 100 feet; similar remains are known round San Francisco; not only shell-beds but molluscan borings also occur on the coast of the bay at various heights above the sea, but they nowhere appear to extend above 100 feet (30·8 meters) [4].

East of the town of Santa Cruz, south California (lat. 36° 55′ N.), according to Whitney, two particularly long and distinct terraces are visible at a height of 64 and 263 feet (19·5 and 80 meters); the lower terrace forms a fairly broad plain on which the town of Santa Cruz is built. The Santa Maria cañon (about lat. 34° N.) is terraced at its mouth down to

[1] J. D. Dana in C. Wilkes, U. S. Exploring Expedition during the years 1838 to 1842, 1849, X, pp. 670, 677.

[2] W. A. Goodyear, Notes on the Geology of the Coast of Oregon; Proc. Cal. Acad. Sci., 1872, IV, pp. 295–298.

[3] G. Becker, Notes on the Stratigraphy of California, Bull. U. S. Geol. Surv., 1885, No. 19, pp. 15, 16. Davidson mentions a horizontal terrace at a height of forty feet at point Arena; Proc. Cal. Acad. Sci., 1871, IV, p. 179, and in particular, The Abrasions of the Continental Shore of North-west America and the supposed ancient Sea-levels, op. cit., 1873, V, pp. 90–97 and pl. v. The same observer cites numerous observations relating to terraces on the coast of California and in more northerly latitudes; he believes that they have been produced by a universal ice-mantle. I must refrain from making use of these data, because, as the author himself admits, a great part of the observations were made from the open sea.

[4] J. Blake, On the Gradual Elevation of the Land in the Environs of San Francisco, Proc. Cal. Acad. Sci., 1863, III, pp. 45, 46; Newberry, Report on North California and Oregon, 4to, 1857, pp. 13–15; Whitney, Geology of California, 1865, I, p. 102; Amos Bowman, On Coast, Surface, and Scenic Geology, Proc. Cal. Acad. Sci., 1872, IV, p. 244.

the sea; the highest of the four steps lies at a height of 148 feet (45 meters), and Newberry confirms the presence of recent shell-beds at several localities on this coast[1].

In the most northerly part of the gulf of California a number of most remarkable changes appear to have occurred. According to Blake's description there can be little doubt that this gulf once extended much further into the land to the north-west, that is, in the same direction as that in which the chains of south Arizona, coming from the south-east, meet the ranges of lower California. It is in this region that a considerable part of the Colorado desert now lies at or below the level of the sea. Scanty remains of a somewhat curious marine Tertiary deposit are known on its western border; they contain Ostrea, Anomia, and Pecten. The whole central part of the desert is now filled with an argillaceous fresh-water deposit containing Anodonta, Planorbis, Physa, Amnicola, and towards the south, Gnathodon also. Terraces occur here and there near its margin.

The Colorado river flows above the level of the desert, of which it forms approximately the eastern boundary, and from the neighbourhood of its bed the country slopes gently towards the bottom of the desert basin. Blake has shown that in all probability the finer sediments of the river accumulated in the fresh-water lake which once occupied the site of the desert, while its coarser sediments were deposited nearer its banks; by the mere growth of these deposits first the sea became shut out from the lake, and next the lake cut off from the river; the lake, desiccated by evaporation, has now become the desert[2].

The observations at my disposal concerning the southern parts of the gulf are not of great importance.

Remond mentions shell-beds in the neighbourhood of *la Paz* and at *Mazatlan*, which occur some meters above the sea, and contain existing

[1] J. D. Whitney, Geology of California, I, pp. 165, 169. Whitney, quoting Dr. Cooper, mentions terraces on the islands of St. Barbara and Cataline (lat. 34°–33° 20′ N.) even up to a height of 1,000 feet, but he has not visited the localities himself; tom. cit., p. 182. The strand-lines of Monterey are already mentioned by Blake, Reports of Explorations and Surveys for a Railroad from the Mississippi River to the Pacific Ocean, V, 1856, pp. 129, 186. Near San Pedro an elephant's tooth is said to have been found in the ancient littoral deposits. Oscar Loew believes that south California is rising at present at the rate of five feet in the century; see Loew in Wheeler, Annual Report upon the Geographical and Geological Explorations and Surveys West of the 100th Meridian, 8vo, 1876, p. 184. For meteorological reasons he further concludes that Mexico, Arizona, and east California are sinking, while Utah and the Californian coast are rising. It seems doubtful, however, whether it is possible to draw such conclusions from the rainfall; tom. cit., p. 178.

[2] Blake, Pacific Railroad Reports, V, pp. 228–240; see also Newberry in J. C. Ives, Report on the Colorado River of the West, 4to, Washington, 1861, Geological Report, pp. 19 et seq.

species. Unless these should prove to be kitchen middens we here encounter signs of negative movement within the tropic of Cancer [1].

Further south data of this kind are wanting, but we soon meet with an indication of an opposite character. According to the observations of Lieutenant Griswold, published after his death by Harper Pease, *Clipperton rock* (lat. 10° 17′ N., long. 109° 19′ W.) must be regarded as a true atoll. A broad and continuous girdle of coral reef rises from a great depth to about fifteen feet above the sea and encloses a lagoon. On the south side of the lagoon there rises to a height of 120 feet a weathered splintery grey volcanic rock tunnelled with caves and connected with the reef by a narrow tongue of coral clinkers. The lagoon is a tranquil lake of almost fresh water; it measures two nautical miles in length and one in breadth [2].

5. *Conclusion.* We have now passed in review the coasts of the northern seas, and after rejecting the deceptive evidence afforded by kitchen middens, ice-dammed fjords, river terraces, and much else, we recognize throughout these regions manifold evidence of a negative movement of the strand-line. It is in high latitudes that the remains of subfossil shells attain the greatest altitude, and towards the south the signs of displacement become less numerous.

From the polar regions, proceeding along the west Atlantic coast, we have traced these indications in the form of terraces and as the postglacial deposits of the Champlain beds; Dana lays stress on their decrease in height towards the south. At about the fortieth parallel they are no longer of any importance.

In like manner we have traced them towards the south along the coasts of the east Atlantic, where they encroach on the coastal region of northern Russia, and then spread over the lowlands of Scandinavia into the north of Germany. Even as far south as Christiania it is estimated that the sea-level still retained a height of 600 feet, but a lower horizon which occurs at a height of 120 feet contains a molluscan fauna closely approaching that now in existence, and it is this stage which attains the widest distribution. Owing to the great complexity of the phenomena presented by the Mediterranean it is difficult to say to what extent this negative movement is revealed there. At the same time it must be borne in mind that the presence of northern immigrants in the South probably corresponds to the greatest extension of the ice, that in Sweden the shell-beds with Arctic mollusca are more recent than this extension, and that further

[1] Remond, An. Univ. Chili, 1868, XXXI, p. 416.

[2] Harper Pease, On the existence of an Atoll near the West Coast of America, and Proof of its Elevation; Proc. Cal. Acad., 1866, III, pp. 199-201. I have not been able to understand how Pease deduces from Griswold's description an elevation of the atoll to the extent of 100 feet.

north the Arctic fauna of the high-lying shell-beds still maintains its existence at the present day.

On the east coast of Asia we found terraces occurring at a moderate height in Japan, and following Richthofen we may place the limit of well-defined displacements of the strand in about the latitude of the Tshu-san islands (lat. 30° N.).

More than fifty years ago Dana observed that traces of a great change in the relative position of land and sea occur on the west coast of America as far down as the fiftieth or even forty-fifth parallel, and that towards the equator these traces grow rarer or altogether disappear, or indicate displacement of an opposite sign [1].

This conclusion that a displacement which was on the whole negative has taken place about the pole, coincides with the results of Howorth (II, p. 20) and other observers. The precise nature of the movements cannot, however, be determined. It is difficult to say whether they were uniform, spasmodic, or oscillatory; the last seems most probable. The bands of 'Noah-wood' indicate some extraordinary disturbance of the tides, which was independent of the sea-level, whatever that may have been, and which might even have occurred during a negative displacement moving at an absolutely uniform rate. Even terraces do not afford a complete proof of spasmodic displacement. Greater importance attaches to the fact that in Sweden the lower shell-bed is sharply distinguished from the upper by its fauna, and that in the north of Norway it may be recognized as readily by its colour as its fossils. A fact even still more striking is that in the Bermudas, i. e. within the region and within the period under consideration, we meet with signs of positive movement (II, p. 313).

The first signs of the approach of a cold climate are furnished by the northern mollusca, which make their appearance in the English 'Crag,' i. e. the highest beds of the Tertiary succession. An increase in the number of Arctic immigrants followed; then came the great glaciation. This, however, was interrupted by oscillations, during which the ice disappeared, a fairly temperate climate prevailed, and extensive forests and great terrestrial mammals flourished. The ice returned, but did not advance so far as previously; now for the first time we recognize with some degree of certainty the shores of a sea which rose around Scotland to a height of about 200 meters, and from this time onwards we obtain a clearer insight into the movement, mainly negative, which has been the subject of our study. The molluscan fauna still remained Arctic. It is not until later, at a lower horizon, that a few southern immigrants make their appearance in Sweden. In America we already see the influence of the Gulf stream. The fauna of the shell-beds on the lower Yenisei described by F. Schmidt bears so great a resemblance to the existing

[1] Dana in Wilkes, U. S. Exploring Expedition, &c., 1849, X, pp. 670, 677.

Arctic fauna that we are compelled to regard them as identical. From the same investigations it is plainly evident that the bodies of mammoths which are found in the tundra were washed into lakes or marshes of more recent date than the shell-beds, i.e. that a considerable part of the negative movements had already taken place at a time when the mammoth still lived and flourished. Near Calais also we have found remains of the mammoth above the existing marine mollusca (II, p. 416).

Whatever uncertainty there may be in matters of detail, the general conclusion seems clear that in all the northern seas the strand stood higher towards the close of the glacial period than it does at present; indeed, that long after the ice age had passed away, and at a time when the molluscan fauna had already assumed its existing character, a somewhat higher level of the strand-line prevailed over the whole region; the negative excess of the movement, which was probably oscillatory, was considerable in the north, but decreased towards the south. But even in these seas displacements susceptible of measurement have not occurred within the historic period.

CHAPTER XIII

STRAND-LINES OF THE EQUATORIAL AND SOUTHERN COASTS

Western coasts of the Atlantic Ocean, central and southern part. Eastern coasts of the Atlantic Ocean, African part. Coasts of East Africa and Arabia. Coasts of India and Further India. Coasts of the Polynesian islands and Australia. West coast of South America.

1. *Western coasts of the Atlantic Ocean, central and southern part.* We will begin at cape Hatteras. The Champlain deposits of the north have disappeared; the terraces have become much lower. In *South Carolina* peculiar phosphate beds occur which lie horizontal and extend over a wide area; they contain remains not only of Mastodon and Elephas, but also of the sperm whale, and probably the walrus, as well as stone weapons and traces of domestic animals; Leidy regards them as the accumulations of a long period deposited over a low shore [1].

The arguments which serve to disprove any measurable movement at the present day in the Carolines, in *Florida*, and at the mouths of the Mississippi have already been stated; at the same time attention has been directed to a shelly breccia which, reaching a height of ten to twelve feet, occurs along the whole east coast of Florida, and is regarded as an indication of a recent negative movement (II, p. 311).

As early as 1853 Lyell drew attention to the striking regularity of the S-shaped line which unites the trend of the Bahamas with that of the Lesser Antilles, and Nelson's descriptions have led us to suppose that an ancient core exists within these islands. Gabb declared that all the Bahamas, especially the higher-lying parts, are the separated but still horizontal fragments of an originally continuous region. Here and in the Antilles an attempt has been made to distinguish as a separate formation a more recent post-Pliocene littoral limestone, which Gabb proposes to call 'Antillite'; I confess that the limit between the more recent marine deposits and the Tertiary formations does not seem to me to have been

[1] J. Leidy, Description of Vertebrate Remains, chiefly from the Phosphate Beds of South Carolina, Journ. Acad. Sci. Philadelphia, 1877, 2nd Ser., VIII, pp. 209–261; Brylinski, Phosphates de chaux de la Caroline du Sud, Bull. Soc. géol. de Normandie, 1875, II, pp. 3–74; for a comparison with the phosphate beds of the English Chalk, see A. J. Jukes-Browne, Quart. Journ. Geol. Soc., 1875, XXXI, pp. 256–314.

drawn with sufficient sharpness in this region. The observations made at Sombrero seem to indicate repeated oscillation (II, p. 311); in Antigua we meet even with Miocene beds, of the age of the Orbitoides limestone, which project into the sea as reefs. The difficulties encountered in attempting to distinguish the latest movements are the same here as in the Mediterranean; we must, therefore, confine ourselves to the statement that at present we do not possess any proof of a sensible change of level, and that the living coral reefs exclude all idea of an existing negative movement; nevertheless, there are abundant indications of previous negative displacements, of which a more or less considerable part date from the Tertiary aera [1].

The coasts of *Guiana* are very unfavourable for observations of this kind; they are flat and extend in a gentle slope beneath the sea, as at Georgetown, for example; sand-dunes at a distance of several miles from the coast-line separate this flat shore from the interior [2].

On the north coast of *Brazil* the shore recedes to some distance beyond the mouth of the Paranahyba. Da Silva Coutinho, who gives a vivid description of this feature, ascribes it either to a subsidence of the land or to an advance of the sea. The mighty stream of the Amazon, despite its load of sediment, is unable to build up a delta; the great islands at its mouths, Marajo, Caviana, and Mexiana, do not consist of recent alluvium brought down by the river, they are indeed fragments of the continent which have been separated by the sea. They are destined to disappear—a fate to which so many other vast regions have succumbed. From the Pará to the Maranhão the destructive advance of the waves takes place in a network of canals and lagoons. When Da Silva Coutinho visited this region in 1867 the sea already washed against two lighthouses which had been built about thirty years before at a distance of 500 meters inland. The tide enters the various arms and channels of the river with irresistible

[1] R. J. Nelson, On the Geology of the Bahamas and on Coral-Formations generally, Quart. Journ. Geol. Soc., 1853, IX, pp. 200–215; C. Lyell, tom. cit., note, p. 202; W. M. Gabb, On the Topography and Geology of San Domingo, Trans. Am. Phil. Soc., New Ser., 1872, XV, pp. 103, 111; Gaussoin, The Island of Navassa, Am. Journ. Nat. Sci., 1867, 2nd Ser., XLII, p. 439. Anegada rises only nine meters high, according to Cleve; the reefs have been described by R. H. Schomburgk, Remarks on Anegada, Journ. Roy. Geogr. Soc., London, 1832, II, pp. 152–170. The recent land in Guadeloupe is described by P. Duchassaing, Essai sur la constitution géologique de la partie basse de la Guadeloupe, dite Grande-Terre, Bull. Soc. géol. de Fr., 1847, 2e sér., IV, pp. 1093–1100, and Observations sur les formations modernes de l'Ile de Guadeloupe, op. cit., 1855, 2e sér., XII, pp. 753–759; Darwin, Coral Reefs, p. 261; Schott, Die Küstenbildungen des nördlichen Yukatan, Peterm. Mitth., 1866, XII, pp. 127–130; Gabb, Notes on Costa Rica Geology, Am. Journ. Nat. Sci., 1875, 3rd Ser., IX, p. 203. Gabb describes inland terraces on the river Mao east-south-east of Sabaneta, San Domingo; they do not belong to this series of formations; cf. Gabb, loc. cit., p. 63.

[2] J. G. Sawkins, Observations on British Guiana; Quart. Journ. Geol. Soc., 1871, XXVII, pp. 419–434.

force and takes permanent possession of the ground. Marine animals establish themselves in places formerly covered by fresh water, and long lines of mangroves advance towards the continent, while the flora of the dry land recedes [1].

Such is the order of events which may be followed here beneath the equator; but it is difficult to discover how much of this process must be really ascribed to a positive movement of the strand, and how much to the action of the waves.

The island of *St. Paul*, far out in the Ocean, has furnished no definite results. At the edge of the breakers Wyville Thomson observed a red band of encrusting nullipores [2].

East of the Maranhão lies the region of the *Brazilian coral reefs*; passing cape St. Roque, it embraces the group of the Abrolhos and reaches Cabo Frio, thus extending from lat. 1° or 2° to lat. 22° or 23° S.; our knowledge of this region is of recent date, and is chiefly due to Hartt. The species composing the reefs are almost all peculiar to this coast. There are many forms representative of those of the West Indies, and closely allied to them, but a large number of characteristic genera are absent. The most important genera are Acanthastraea, Favia, Heliastraea, Siderastraea, Porites. Cabo Frio may be regarded as the most southerly point at which they occur; in the bay of Rio Janeiro, in spite of apparently favourable conditions, there are only one or two species of Astrangia. But as far as the Abrolhos, that is to about lat. 18° S., bands of true coral reef are to be seen along the coast, succeeding one another at irregular intervals. They are generally separated from the mainland by a navigable channel [3].

The observations relating to movements of the strand-line on *San Fernando de Noronha* (lat. 3° 50′ S.) are most contradictory. The principal mass of the island consists of basalt and phonolite, the little island of Booby is formed of calcareous sandstone. The presence of an ancient high-water line and certain eroded cavities in Booby island led Rattray to conclude that the group had been recently elevated. On the other hand, Buchanan, who subsequently visited the group with the *Challenger*, points out that the stratification on Booby island has been produced by the wind, and as it extends beneath the sea, he concludes that the land has sunk or is still sinking [4].

[1] Da Silva Coutinho, L'Embouchure de l'Amazone; Bull. Soc. géogr. Paris, 1867, 5e sér., XIV, pp. 321–334.

[2] C. Wyville Thomson, The Voyage of the *Challenger*, 8vo, 1877, II, pp. 105, 108.

[3] C. F. Hartt, Remarks on the Brazilian Coral-Fauna, Trans. Connect. Acad., 1866–1871, I, p. 364 (in the appendix to Verrill, Notice of the Corals and Echinoderms collected by Prof. Hartt at the Abrolhos Reefs, tom. cit., pp. 351–364); also, by the same, Geology and Physical Geography of Brazil, 8vo, Boston, 1870, pp. 189, 204.

[4] A. Rattray, On the Geology of Fernando Noronha, Quart. Journ. Geol. Soc., 1872,

A fact of more importance for our inquiry is furnished by the *Roccas* group, which lies between Fernando de Noronha and the mainland; according to Hartt's account it presents all the characters of a typical coral reef formed under positive movement of the strand-line.

Along the coast the reefs of *Pernambuco* (lat. 8° S.) have been described by Hawkshaw; he regarded them as indicating intermittent movement. The reefs of Parahyba do Norte (lat. 7° S.) and the island of Itaparica, near Bahia (lat. 12° 50′ S.), have been examined by Rathbun. At Itaparica the base of the reefs is formed by corals; above these come nullipores and innumerable tubes of Serpula which are especially abundant about the summit. The reefs are separated from the land by a channel, in which lie dead corals encrusted by nullipores and Serpulae; in the bay of Bahia all the corals, with the exception of *Mussa Harttii*, appear to belong to still existing species. A large part of the reefs is exposed at low tide; Hartt expressly mentions this, as, for instance, when describing the irregular coral reefs which occur outside the town of Maceió (province of Alagoas), and continue northwards to Pernambuco [1].

In the *Abrolhos* fringing reefs occur; the island of Santa Barbara, for instance, is surrounded by one. Hartt's detailed description of the reefs of Lixo, lying to the north-west of the preceding, shows that these present a horizontal surface of dead coral, traversed by deep channels, and rising two feet above low water, though submerged at ordinary high tide. 'The reef,' says Hartt, 'grew as high as it could, and is now dead; . . . its height must probably be ascribed to a recent elevation of the land.'

Along the coast of Brazil 'chapeiroes,' i. e. sea-stacks formed of corals, rise from the Ocean; they are only a few meters in diameter, but sometimes unite to form extensive reefs; the largest reefs are surrounded by such stacks. As a rule, the reefs rise a little above low water, and present a remarkably even surface; sometimes, but rarely, they are covered with soil [2].

These facts would seem to suggest that this part of the coast has been affected by a negative movement which has exposed the coral reefs and killed them.

The observations made by Hartt on the mainland accord fairly well with this interpretation. Somewhat north of the Santa Cruz river large areas are covered by dead corals which are exposed at low water. At the

XXVIII, pp. 31–34. According to the statement of this author granite also occurs in considerable masses; Buchanan, in The Voyage of the *Challenger*, II, p. 119.

[1] J. Clarke Hawkshaw, Notes on the Consolidated Beach at Pernambuco, Quart. Journ. Geol. Soc., 1879, XXXV, pp. 239–243; R. Rathbun, Notes on the Coral Reefs on the Island of Itaparica, Bahia, and of Parahyba do Norte, Proc. Boston Soc. Nat. Hist., 1878, XX, pp. 39–41, and Am. Journ. Nat. Sci., 1879, 3rd Ser., XVII, p. 326.

[2] Hartt, Remarks on the Brazilian Coral-Fauna, p. 364; Liais, Compt. rend., 1860, L, p. 762; and Marcel de Serres, tom. cit., p. 907.

mouth of the Jequitinhonha, near Belmonte (not far from Porto Seguro), ancient strand-lines are visible along the flat coast. Similar traces appear on the *Pão d'Assucar* near Victoria in the province of Espiritu Santo.

For reasons already frequently mentioned, I do not attach much importance to the presence of a submerged forest south of the mouth of the Mucury river, west of the Abrolhos [1]. The conclusion which might be drawn from it would be diametrically opposed to all the preceding evidence.

At *Cabo Frio*, and to the south of it, the traces of negative movement increase, but the data must be carefully examined, since the height of the beds above sea-level is inconsiderable and kitchen middens occur, as well as the remains of sepulchral monuments and other indications of an ancient settlement. Accounts even are in existence which attribute an artificial origin to the bar at the mouth of the harbour of Cabo Frio [2].

On the Maricas islands, between Cabo Frio and Rio, Hartt observed the empty cup-shaped holes of *Echinometra Michelini* in the gneiss of the cliffs, and in the bay of Rio itself he found sand with recent shells several feet above high water; similar formations also occur in the marshes of the province of São Paolo [3].

At Laguna, Capanema mentions oysters adhering to the granite rocks a little more than two meters above high water. All the 'sambaquis' or shell heaps of this region must, however, be regarded as the relics of human occupation. Above Buenos Ayres shell-beds six or eight meters above the level of the La Plata are worked as limestone quarries; they contain remains of whales, but also of ancient pottery. This does not, however, imply that indications of negative movement are absent; on the contrary near Rosario, much higher up in this same river basin, Stelzner encountered brackish-water shells several meters above the water level [4].

On the *La Plata*, between lat. 33° and 35° S., we enter that remarkable terraced land which stretches with terraces progressively increasing in height till we pass beyond the straits of Magellan. According to Darwin, we may see in some places five terraces, in others seven or eight, perhaps even nine. It is doubtful, however, whether the river terraces have in all cases been sufficiently distinguished from the marine. This is the region in which Doering's quer-Andinian stage occurs. It is probably the equi-

[1] Hartt, Geology and Physical Geography of Brazil, pp. 220, 221, 224.

[2] Annalen der Hydrographie, 1878, VI, pp. 170–171.

[3] Hartt, Geology and Physical Geography of Brazil, pp. 35, 71, 506.

[4] G. S. de Capanema, Die Sambaquis oder Muschelhügel Brasiliens, Peterm. Mitth., 1874, XX, pp. 228–230; Wiener, Mitth. k. k. geogr. Ges. Wien, 1876, 2. Ser., IX, pp. 486–489; K. Rath, Globus, XXVI, p. 194; Heusser et Claraz, Essais pour servir à une description physique et géognostique de la Province Argentine de Buenos-Ayres, 4to, Zürich, 1865, II, pp. 108–139; Stelzner in Napp, Die Argentinische Republik, 8vo, Buenos-Ayres, 1876, p. 84.

valent of the Champlain stage of the north. Both are crowded with marine shells belonging to the existing fauna, and both rise to a greater and greater height as they proceed towards the pole. In the bay of la Plata these shell-beds lie at a height of 20 to 30 meters, but in the extreme south at 100 meters, and in the latter case the accompanying terraces rise to a height of 300 to 400 meters (II, p. 308).

Roger and Ibar, crossing the mountains from Skyring water, found that near the sources of the Rio Gallegos (lat. 51° 45′ S.) the chain is suddenly replaced by tabular hills; these are all of equal height, and like those described by Captain FitzRoy on the Rio Santa Cruz look as though they were the remains of a table-land which had been broken up by the excavation of the river valleys[1].

Thus we learn from the east coast of America that the terraces disappear south of lat. 40° N.; faint traces of negative movement occur in Florida; no definite information is afforded by the Antilles, but the presence of living reefs proves the absence of existing negative movement. Guiana likewise furnishes nothing definite, but the terraces are absent. At the mouth of the Amazon the sea encroaches on the land, perhaps owing to the erosive action of the breakers. Then coral reefs begin to appear; towards the south they are dead, probably owing to a negative movement, and at low water they are exposed to the air.

Further south the indications of negative movement become somewhat clearer; on the la Plata between lat. 30° and 40° S. the terraced land of the north again makes its appearance and the quer-Andinian stage rises higher and higher above the sea as it proceeds to the south, just as the Champlain stage and the terraces accompanying it increase in height towards the north.

2. *East Atlantic coast, Africa.* The accounts at my disposal relating to this coast are few in number, and for the greater part indefinite in character. According to Maw, an ancient strand-line is to be seen at many points on the coast of Morocco; it corresponds to a similar coast-line on Gibraltar; Maw observed it at heights of about 40 to 60 or 70 feet south of cape Spartel in the bay of *Tangiers*, and at Mogador. Further south from about lat. 29° 30′ to 28° N. the coast has been visited by Duro; in this region it consists of interrupted cliffs formed of white and red sandstone. The ruins of the Spanish fort, called by the natives Tagadir Rumi, which once rose south of *Cabo Non*, are fast disappearing; the projecting cliff on

[1] R. FitzRoy, Extracts from the Diary of an Attempt to ascend the River Santa Cruz in Patagonia, Journ. Roy. Geogr. Soc., 1837, VII, p. 114; also Travels of the *Adventure* and *Beagle*, II: Darwin, as is well known, accompanied FitzRoy. Roger i Ibar, Estudios sobre las aguas de Skyring, por el Comandante i Oficiales de la Corbeta 'Magellánes,' 8vo, Santjago, 1878, p. 66. Captain Musters also observed strongly marked terraces on the Gallego; less clear, but likewise recognizable, are those on the Cuheyli, which flows into Coy inlet; J. C. Musters, Unter den Patagoniern (German ed.), 1873, passim.

which it stood was undermined by the sea, and this—not, as some observers have thought, a subsidence—was the cause of its destruction. Similar evidence is to be seen at the Wady Draa. On climbing the cliff we look over the plain extending further than the eye can reach [1].

The *Canary islands* also present signs of negative movement; as such I regard the remains of shells mentioned by Fritsch as occurring on the island of Palma at a height of +20 to +40 feet; they are cemented together by sand and clay and fill the joints and crevices in recent basaltic cliffs. As to the high-level deposits which occur on all these Atlantic islands, there is a difficulty as to their age; they may be Tertiary, but it is impossible to arrive at a definite conclusion from the existing accounts [2].

At *cape Blanco*, according to Belcher, the atmosphere is densely charged with sand; of vegetation there is next to none: less than a month suffices for the sand to bury large buildings out of sight. Marine shells are found distributed in great quantities at a considerable height above high tide [3].

Shell-beds of comparatively recent age are found on several of the *Cape Verde islands*; they have been described by Darwin; Fischer has studied their fauna from collections made by Cessac, who obtained most of his specimens from São Jago, where the beds lie at a height of +18 meters, intercalated between two sheets of basalt; with two exceptions the shells belong to living species [4].

About the *Mel islands* [Bissagos islands] (lat. 12° N.) coral reefs are to be seen which descend steeply to great depths; long bars and lagoons border the coasts from long. 1° 15′ to 1° 34′ E. [5]

[1] G. Maw, Notes on the Geology of the Plain of Marocco and the Great Atlas, Quart. Journ. Geol. Soc., 1872, XXVIII, pp. 85–97, in particular pp. 86, 87; C. F. Duro, Exploracion de una parte de la costa noroeste de Africa, Bol. Soc. Geogr. Madrid, 1878, IV, pp. 184–199; W. Arlett, Survey of some of the Canary Islands and part of the Western Coast of Africa, Journ. Roy. Geogr. Soc. London, 1836, VI, pp. 285–310.

[2] K. von Fritsch, Zeitschr. deutsch. geol. Ges., 1862, XIV, p. 547. Here even fragments of coral and shells are mentioned at a height of 700 feet. I should be inclined to regard them as Tertiary.

[3] Belcher, Extracts from Observations on various Points of the West Coast of Africa, surveyed by H.M.S. *Aetna*; Journ. Roy. Geogr. Soc. London, 1832, II, p. 301. The coast is described by Aube, L'Ile Arguin et les pêcheries de la côte occidentale de l'Afrique; Rev. marit. et col., 1872, p. 470.

[4] Darwin, Geological Observations, 2nd ed., pp. 4–6; P. Fischer, Sur les fossiles des îles du Cap Vert, rapportés par M. de Cessac, Compt. rend., 1874, LXXVIII, pp. 503–506; Baron von Barth, Primo Relatorio da Commissão encarg. de explor. geol. de la Provincia de Angola, Ann. da Comm. centr. perm. de Geographia, Lisboa, 1876, No. I, pp. 35–37. In the South Atlantic, on Nightingale Island (Tristan d'Acunha group) Buchanan observed a shore-line at a height of 10·8 meters, and the negative traces appear to extend much higher; Proc. Roy. Soc. London, 1876, XXV, p. 614.

[5] U. S. Hydrographic Office, The West Coast of Africa, 1873, I, pp. 160, 190; Langhans, Peterm. Mitth., 1885, XXXI, p. 211, pl. xi. At cape Palmas there can hardly be either coral reefs or shell-beds of any size, for the senate of Palmas has offered a reward for the

South of the *mouth of the Congo*, Pechuel-Lösche found limestone containing oyster shells; it forms cliffs along the coast twenty feet in height, but I have no information as to their age [1].

There are numerous accounts treating of the structure of the west coasts of Africa, but in general our knowledge of these regions is extremely incomplete; even the shell-beds found a little above the sea-level at the mouths of the Senegal and also, far remote from this river, in the lagoon of Assini, which are described by Pomel as Quaternary, may possibly be only ancient kitchen middens [2].

The accounts at my disposal which refer to the more southern part of the coast are quite inadequate, but in *Cape Colony* the evidence of negative movements is very definite. Clarke long ago recorded the presence of parallel strand-lines and of high-lying shell-beds in the neighbourhood of Cape Town; he considers that the district around False bay, as well as Table bay, must have been covered by more than sixty fathoms of water, converting the Cape into an island [3].

We are thus in a position to state that, from Gibraltar to beyond the Cape Verde islands, traces of negative movement are known to occur at a moderate height above the sea; further south information is wanting or inadequate; but in Cape Colony signs of negative movement are very obvious.

3. *Coasts of eastern Africa and Arabia.* The traces visible at Cape Town are repeated at many localities in South Africa. Stow, who has very carefully studied the most recent marine deposits, includes among them sloping surfaces of quartzite worn by erosion which occur in the neighbourhood of *Port Elizabeth* at a height of 180 feet (55·5 meters), and marine sands in which shells have been found up to a height of 60 or 70 feet. Again, at Reuben point, at the entrance to Delagoa bay, the recent marine sands with shells lie, according to Cohen, at a height of 40 meters, and extend 25 kilometers into the interior. Griesbach states that on the whole east coast of Africa signs of a recent elevation of the land occur; but since remains of human occupation have been found in the supposed ancient

discovery of limestone; Schönlein, Zeitschr. deutsch. Ges. Erdk., Berlin, 1875, X, p. 431. D. Dohrn has kindly informed me that he noticed no traces of an altered strand-line on Princes island; nor does O. Baumann know of anything similar at Fernando Po.

[1] O. Lenz, Petrefakten von der Loangoküste, Verh. k. k. geol. Reichsanst., 1877, p. 279. From Zboïnski on the lower Congo subfossil mollusca of living species are said to have been obtained at a height of 200 meters; Bull. Soc. belge Géol., 1887, I, Procès-verb., p. 30. There may be some misunderstanding here; Herr Baumann tells me that such heights only occur at some distance inland; he had climbed them but seen nothing of the kind.

[2] A. Pomel, Le Sahara, p. 25.

[3] M. B. Clarke, On the Geological Phenomena in the Vicinity of Cape Town; Proc. Geol. Soc., 1838–1842, III, p. 422. In the island of Kerguelen there is a continuous terrace at a height of 6 meters; T. Studer, Zeitschr. deutsch. geol. Ges., 1878, XXX, p. 346.

littoral formations at various localities close to the shore at Natal, at Inanda, and at the mouth of the Zambesi, it is probable these beds are to a great extent simply kitchen middens [1].

Griesbach believed he had observed elevated coral reefs more to the north around the island of Marsha, and he ascribes the origin of the Bazaruto islands to an elevation of coral reefs. The town of *Mozambique* is built on a flat, low-lying coral formation, and the somewhat antiquated, but detailed descriptions furnished by Lieut. Wolf of H.M.S. *Leven* and *Barracouta* show clearly that, as we proceed towards the north, the coast becomes increasingly fringed by true coral reefs.

Attention has frequently been called to the great depths to which the coral reefs suddenly descend on the seaward side. In lat. 12° 20′ S., near Ibo, the reef is separated from the mainland by a lagoon. Cape Delgado (lat. 10° 41′ S.) and the Querimba islands, the harbour of Quiloa, the islands Mafía and Pemba are examples which illustrate the steep descent of the sides of the reef to great depths. At Mombasa a lagoon lies between the reef and the mainland. In spite of these indications it cannot be denied that signs of negative movement also exist even on the very coasts which are bordered by barrier reefs. Burton states that the Mrima, i. e. the coast north of *Zanzibar*, shows signs of an elevation of the land extending from Rufiji to Mombasa, and in places there are even distinct traces of two strand-lines which are separated by a flat terrace. Thomson gives a precisely similar account of this coast at Dares-Salaam (lat. 6° 50′ S.); he says there are two, if not three, successive littoral zones; between the first and second the upward movement must have been temporarily arrested. Still further north, opposite the island of Kiama (lat. 0° 40′ S.), Brenner found that the coral formation extends more than 3 kilometers inland, and then suddenly terminates in a range of wooded hills formed of dune sand [2].

[1] G. W. Stow, Some Points in South African Geology, Quart. Journ. Geol. Soc., 1871, XXVII, pp. 520, 522; the older work of Kraus even mentions oysters at a height of 600–700 feet on the grass rüggens between Uitenhage and Grahams Town; Ueber die geologischen Verhältnisse der Ostküste des Caplandes, Amtl. Ber. XX. Versamml. deutsch. Naturf. und Aerzte, Mainz. 1842, p. 129; Bain says 20 to 300 feet, Trans. Geol. Soc., 1845, 2nd Ser., VII, p. 191; E. Cohen, Erläuternde Bemerkungen zu einer Routenkarte, II. Jahresb. geogr. Ges. Hamburg, 1875, p. 111; C. L. Griesbach, Geology of Natal, Quart. Journ. Geol. Soc., 1871, XXVII, p. 67; the recent marine sand in Delagoa bay is mentioned by Rehmann, Das Transvaal-Gebiet, Mitth. k. k. geogr. Ges. Wien, 1883, XXVI, p. 389.

[2] (Lieut. Wolf,) Narrative of Voyage to explore the shores of Africa, Arabia, and Madagascar, performed in H.M.S. *Leven* and *Barracouta* under direction of Capt. W. F. W. Owen, 8vo, London, 1832, I, pp. 187, 379, 425, 427; II, pp. 2, 5, 9, et passim; Darwin, Coral Reefs, p. 76; Burton, The Lake Regions of Central Equatorial Africa, Journ. Roy. Geogr. Soc., 1859, XXIX, p. 35; J. Thomson, To the Central African Lakes, 8vo, 1881, I, pp. 75, 94; R. Brenner, Peterm. Mitth., 1868, XIV, p. 362. The coral ground of Zanzibar is described by v. d. Decken, Reisen in Ost-Afrika, 8vo, 1869, I, p. 22.

The presence of relict strand-lines on coasts bordered by lagoons and barrier reefs with steeply descending walls can scarcely cause us surprise, since, in the Pacific Ocean, we have become acquainted with fragments of table-land which rise 100 meters above the sea, have been laid dry by negative movement, and are at present engirdled by lagoons and living barrier reefs.

A large part of *Madagascar* is surrounded by a barrier reef; according to Wharton the Farquhar islands (João de Nova), north of Madagascar, form an atoll with a lagoon; in like manner, according to Coghlan's account, the Abbé bank, north of Mauritius, forms an elongated atoll; this, however, is quite submerged, and its surface lies at a depth of −13 to −18 meters; in this it resembles many other coral reefs to the north of Mauritius. Niejahr states that the Cosmoledo islands are so disposed in a circle as to very nearly enclose a lagoon [1]. All the islands surrounding Madagascar from the Comores to the Seychelles as far as Réunion and Mauritius are, with very few exceptions, surrounded by reefs; but on *Mauritius* in particular indications are described of negative movement. On *Rodriguez* an ancient strand-line may be seen at a height of twenty feet [2].

Further north on the coast of Africa, beyond lat. 10° N., the signs of negative movement reappear in a most striking manner. From the evidence afforded by the coast of Medjertines in *North Somali land*, Revoil has even attempted to reconstruct the boundary of the sea at the time it extended over the north coast of the peninsula of Bender Gâsem, Bender Khôr, and Mêraja. Haggenmacher, travelling inland from Berbera, met with weathered beds of oysters and corals two to four hours' journey from the existing coast [3].

The indications observed on the south coast of the gulf of Aden are the precursors of those traces of negative movements which everywhere surround the *Red sea*, and which long ago attracted the attention of travellers.

[1] Grandidier, Notes sur les côtes sud et sud-ouest du Madagascar, Bull. Soc. géogr. Paris, 1867, 5e sér., XIV, pp. 384–394; Sibree, The Great African Island, 1880, p. 36. The observations of Guillemin as to a belt formed of fragments of basalt on the beach probably indicate volcanic drift; Ann. Mines, Paris, 1866, 6e sér., X, p. 281; Comm. Wharton (*Shearwater*), Hydrogr. Notices, 1879, No. 1; Lieut. Coghlan, op. cit., 1877, No. 6; Capt. Friedrich (Brig *Hermann Friedrich*), Ann. d. Hydrogr., 1876, IV, pp. 243–246.

[2] Darwin, Geological Observations, p. 33; G. Clark, Notes on the Geological Features of Mauritius, Quart. Journ. Geol. Soc., 1867, XXIII, pp. 185–190 (a great mass of coral limestone in the interior is said to be formed of species which do not live at present on the shores of the island); R. von Drasche, Die Insel Réunion (Bourbon): eine geologische Studie mit einem Anhang über die Insel Mauritius, 4to, Wien, 1878, pp. 27, 72, 73 (alternation of lavas and beds of corals); Balfour, Gulliver, and Slater, Rodriguez, Phil. Trans., 1879, vol. 168, p. 209; E. Behm, Die Insel Rodriguez, Peterm. Mitth., 1880, p. 287.

[3] G. Revoil, Voyage au pays des Medjourtins, Bull. Soc. géogr. Paris, 1880, 6e sér., XIX, pp. 254–269, and Voyage au Cap des Aromates, 8vo, Paris, 1880; G. A. Haggenmacher, Reise im Somali-Lande, Peterm. Mitth., Ergänzungsheft 47, 1874, p. 18.

As early as 1762 Carsten Niebuhr observed at the wells of Moses that the sea 'appears to have retired to a great distance,' and he noted the same fact on the coast of Djidda. Very early, at a time when Darwin's views on the structure of coral reefs were but little known, Ehrenberg was able to show that in the Red sea the distinction between barrier and fringing reefs could not be maintained with the sharpness it was usually supposed to possess; this, as is well known, was subsequently shown by Dana to be equally the case with the reefs of other regions. As early as 1838 Rüppell attempted to give a general account of the coral beds now exposed above the sea. According to this, their height in the north amounts to +30 or 40 feet; they are continued far to the south, lying horizontally and resting against the ancient rocks. From lat. 26° N. onwards, as at Djidda, Massaua, and elsewhere, they do not attain a height of more than 12 or 15 feet. There is definite proof 'that at one time the height of the sea with regard to the land stood higher in the south by about 15 feet, in the north by about 30 or 40 feet[1].'

Traces of ancient shores at even greater heights have since been found in various localities, but I have quoted the now antiquated description by Rüppell as a token of the deep impression which these long horizontal lines make on a thoughtful observer. They are the same as those which were previously described as marking the apposed or descending series at Suez (I, p. 378). From Suez the line at 200 feet is continued to the Mokattam hills near Cairo, and to Ssedment in the Nile valley; such lines cannot be produced by any movement of the lithosphere.

It is impossible in the present state of our knowledge to give a connected account of the exposed beds or ancient strand-lines which at present surround the Red sea. Only a few localities have been carefully investigated, and most of the observations are unfortunately of too general a character. It is around Suez and in the bay of Akabah—the places most frequently visited—that the highest horizons are known; there can be no doubt, however, that high-lying strand-lines are not of local origin, but have once possessed a very wide distribution.

At Tudjurra, close to the entrance to the Red sea, Rocher d'Héricourt observed recent marine formations at a height of 40 to 50 meters; Aubry encountered two terraces of coral limestone at Obock, one at a height of +15 to 25 meters, the other at 40 to 50 meters; Courbon observed them in the bay of Adulis at a height of 20 to 40 meters. A broad belt of recent marine deposits has been described by Heuglin near Suakim and

[1] Carsten Niebuhr's Reisebeschreibung nach Arabien und anderen umliegenden Ländern, 4to, 1774, pp. 225, 277; Beschreibung von Arabien, 4to, Kopenhagen, 1772, p. 403; Ehrenberg, Ueber die Natur und Bildung der Corallenbänke des Rothen Meeres, Abh. Akad. Wiss. Berlin, 1832, XVIII*a*, pp. 381–432; E. Rüppell, Reise in Abessynien, 8vo, Frankfurt a. M., I, 1838, pp. 140 et seq., 183, 245. and II, 1842, p. 313.

Tokar, and by Botta in Yemen. In Arabia, this belt, which is known as the *Tehama*, borders the coast as far as the strait of Bab-el-Mandeb [1].

It is to Carter that we are chiefly indebted for our knowledge of similar beds on the south coast of Arabia. A Milliolite sandstone, composed of innumerable rhizopod shells, the cavities of which are filled with yellow ferric silicate, borders the coast and extends to Kattyawár on the coast of India; here it is called Purbunder-stone; at Bhooj in Cutch it contains iridescent bivalve shells, and is there called Gold-stone; it is exported from Kattyawár to Bombay as a freestone for building.

This recent marine deposit, so widely distributed, is found plastered at various heights on the precipitous coast of south Arabia, and has been observed up to a height of 150 feet (45·7 meters). In one locality the occurrence of some loose blocks would seem to indicate that it even extended to a far greater height. These, however, are not the only traces of negative movement; borings of Lithodomus may be seen at various heights, and caves likewise, both at the existing level of the breakers and far above it. Thus a cave is described by Carter in the limestone of the Râs Hammar, a part of the Râs Seger (Sejar); it is 150 feet in width and 50 feet high, and the top of its roof is perforated by Lithodomus borings [2].

The traces of this displacement are also continued into the *Persian gulf*; Loftus states that traces of a recent marine deposit containing shells such as still live in this sea may be followed far inland, and indeed that these mollusca may be met with in the lowest beds of the recent alluvium even 400 kilometers away from the existing sea, i. e. 240 kilometers above the confluence of the Tigris and Euphrates. At their summit, however, these marine deposits appear to pass without any sharp line of demarcation into the river alluvium. Against the folded gypsiferous Miocene beds of the outer chains of the Zágros a recent marine deposit of upper Tertiary age rests horizontally; this is Blanford's Makrán group; it extends from Bushire to cape Monze. A much more recent marine formation, the 'littoral concrete,' borders the coast, generally at a height of 20 to 25

[1] Rocher d'Héricourt, Compt. rend., 1841, XII, pp. 732-735; Aubry, Bull. Soc. géol. de Fr., 1886, 3e sér., XIV, p. 201; Courbon, Compt. rend., 1861, LII, pp. 426–433; T. von Heughlin, Reise in N.-O. Afrika, 1877, I, p. 34; Lartet, Géologie de la Palestine, Ann. Sci. géol., 1869, I, p. 263; J. Milne, Quart. Journ. Geol. Soc., 1875, XXXI, p. 8, and in many other publications. On the existing fluctuations of the sea-level, see Klunzinger, Zeitschr. deutsch. Ges. Erdk., Berlin, 1872, VII, p. 21. Malcolmson mentions fossil shells from Aden at a height of more than 100 meters; Vélain has not seen them; C. Vélain, Description géologique de la presqu'île d'Aden et de l'Ile de la Réunion, 4to, Paris, 1878, p. 9.

[2] H. J. Carter, Memoir on the Geology of the South-Eastern Coast of Arabia, Journ. Bombay Branch R. Asiat. Soc., 1852, IV, pp. 21–96; Note on the Pliocene Deposits of the Shore of the Arabian Sea, op. cit., 1853, IV, pp. 445–448, and Summary of the Geology of India between the Ganges, the Indus, and Cape Comorin, op. cit., 1854, V, p. 312.

feet. Bushire is built of it. It forms cape Jáshk in the gulf of Omán. In some places the name is used to designate an exposed coral bed (I, p. 425). The eastern part of the island of Khárak is formed of the littoral concrete; it is surrounded by a coral reef, and the two formations are remarkably similar. These beds are regarded by Blanford as a continuation of the recent coastal deposits which we have just mentioned as occurring on the coast of south Arabia and as far as Cutch [1].

Relict strand-lines thus occur on the east coast of South Africa at a considerable height; in Delagoa bay they still reach a height of +40 meters. Then a gap occurs in the observations, but further north, in Zanzibar, and as far as the equator, distinct indications of an abandoned strand are present, even in those places where lagoons and coral reefs with precipitous slopes bear witness to positive movement in the immediate past. Negative indications are also visible on the coasts of the Red sea, on the south coast of Arabia, and in the Persian gulf.

4. *Coasts of India and Further India.* In turning our attention to the coasts of the Indian peninsula, we must first recall a remarkable peculiarity in the sea-level on the west coast. Towards the south, according to Sowerby, there is little or no tide; in Bombay it amounts to twelve feet, at the mouth of the Tapti to nineteen, at the head of the gulf of Cambay to twenty-eight feet. At this point the Indian tide reaches its greatest height. Many rivers discharge into the gulf, and their sediments, driven back by the tide, form a considerable accumulation on the south-east coast of Kattyawár, between Diu, Jaffrabad, and Goapanath. The bar of the Tapti owes its increase to similar causes. It would thus appear, according to Sowerby's conception, as though Bombay were slowly rising, because new land is formed on the seaward side which checks the entrance of the tide and thus causes a sinking of the mean sea-level [2].

Apart from this, accounts will be found in technical treatises of various alleged elevations and subsidences on the coasts of India.

That the subsidences in *Cutch* are caused by the engulfment and slipping of the moist alluvial land during earthquake shocks has already been mentioned (I, p. 43).

Buist has described a submerged forest at *Bombay*; more recent data relating to it were collected by Ormiston during the construction of docks at the port. The trees are rooted at a level of −12 feet. Blanford

[1] W. K. Loftus, Quart. Journ. Geol. Soc., 1855, XI, p. 251; W. T. Blanford, Note on the Geological Formations seen along the Coasts of Biluchistán and Persia from Karáchi to the head of the Persian Gulf, and on some of the Gulf Islands, Rec. Geol. Surv. India, 1872, V, pp. 41-45; Eastern Persia, 8vo, 1876, II, p. 467 et passim; also Quart. Journ. Geol. Soc., 1873, XXIX, p. 501; W. A. Stiffe, On the Mud-Craters and Geological Structure of the Mekran Coast, op. cit., 1874, XXX, pp. 50-53.

[2] W. Sowerby, Memorandum on the Geological Action of the Sea on the South Coast of Kattyawar; Trans. Bombay Geogr. Soc., 1868, XVIII, pp. 96-104.

remarks in this connexion that the littoral concrete occurs at a distance of no more than a mile from this place. Trees of the species which form the submerged forest (Avicennia and Bruguieria) may be seen living at the present day below the high-water mark; the fact that they are perforated by boring shells seems to indicate a salt lagoon. In my opinion, however, the position of this forest is in no way connected with the movements which laid bare the littoral concrete; the case is comparable with that of the submerged forests of Europe and North America, which owe their position to a local slipping of soft alluvial land [1].

The island of *Vaypi*, on the coast of Malabar, has been cited as a case of recent elevation; as a matter of fact it is a mass of marine sediment which was driven into its present position during an earthquake in 1341 (I, p. 96).

Disregarding the cases just mentioned, we perceive that quite recent marine deposits, comparable with the Milliolite limestone and the littoral concrete, occur, even if only in widely separated patches, all around the Indian peninsula. This was already the conclusion of Buist; it was supported by Blanford and has been confirmed by fresh observations. These patches, which are always horizontally stratified, do not invariably occur at the same height, but in many places the higher horizons have evidently been destroyed. At *cape Monze*, oysters occur attached to the rocks ten to fifteen feet above high tide [2]. Fedden's investigations in Kattyawár show that a narrow belt of upper Tertiary deposits borders the coast as far as the gulf of Cambay, and that outside this belt a zone of Milliolite rock occurs, which extends to a height of over sixty feet, and appears to attain still greater elevations in the interior. The north coast of the peninsula, next the gulf of Cutch, is bordered by dead coral reefs; in spite of the numerous traces of negative movement mentioned by Fedden, I should be inclined to attribute no great importance to this fact, owing to the various influences to which the sea-level is here exposed [3].

Under various forms the Milliolite rock and littoral concrete extend, as we have seen, as far as Bombay. At various localities along the west coast, and far to the south, there may be seen beneath the laterite isolated traces

[1] G. Buist, The Geology of Bombay, Trans. Bombay Geogr. Soc., 1852, X, p. 178; also Evidence of a general Vibration or Descent and subsequent Upheavement of the Land all along the shores from Suez to Arracan, tom. cit., pp. 215–217. H. J. Carter (Notes on the Geology of the Islands around Bombay; Journ. Bombay Branch R. Asiat. Soc., 1862, XXI, p. 176) records a similar fact for Salsette; cf. also op. cit., 1852, IV, p. 166; G. E. Ormiston, Submerged Forest on Bombay Island, Rec. Geol. Surv. India, 1878, XI, p. 302; and Medlicott and Blanford, Geology of India, p. lxxi, note.

[2] W. T. Blanford, The Geology of Western Sind; Mem. Geol. Surv. India, 1879, XVII, p. 184.

[3] F. Fedden, The Geology of the Káthiáwár Peninsula in Guzerat; Mem. Geol. Surv. India, 1885, XXI, p. 53 et seq. Here the Milliolite rock is mentioned far in the interior of the country from the mountain of Chotila, at a height of 1,170 feet; mollusca are not mentioned here; from another place land shells are mentioned in the Milliolite rock. Further investigation is therefore necessary.

of beds lying very near the sea, which have been assigned, but apparently without sufficient reason, to the younger Tertiary; finally, a calcareous sandstone, with a somewhat wider distribution, is exposed near *Quilon*; it has been correlated with the recent Cuddalore sandstone of the east coast. On *cape Comorin*, however, and beyond it, between lat. 8° and 9° N., the negative signs are much more clearly visible. This region and Adam's bridge we will now consider in greater detail, in the case of Adam's bridge with the help of the observations of Foote, supplemented by those of Christopher and Branfill, and by the ancient poems [1].

We meet here, at various levels, with horizontal beds of limestone and calcareous sandstone containing the shells of existing molluscan species. One of the most important areas is the Kudung Kulam plateau, situated a little to the north-east of cape Comorin; it is a table-land about three kilometers in length, surrounded by sand dunes, and reaching a height of 48·5 meters; this is, so far as I know, the greatest height, as ascertained by measurement, at which these deposits occur in the south of the peninsula. Most of the patches by which they are represented occur at very inconsiderable heights, and Foote's opinion that they were formed by a late phase of the negative movement finds support in the observations made in other places. Corals do not appear to occur in these deposits, but on the beach itself and on some of the adjacent islands the upper part of the coral reefs lies high and dry, covered with sand and soil. Precisely similar coral reefs occur in some parts of the island of *Ceylon*. In the interior, says Richthofen, they are not exposed at the surface, but the inhabitants often open up quarries in the coral limestone beneath the fields. The north of Ceylon in particular is said to be entirely underlain by coral formations [2].

A dead coral reef, according to Foote, forms the island of Rameswaram; its surface reaches a height of at least + 3 meters and probably more. This island forms one of the points of attachment of that remarkable bar which is known as *Adam's bridge*. From the dune-covered coast of the peninsula this long mound proceeds first to the south side of the Rameswaram reef, and in this part of its course there occurs near Pámbam an artificially widened channel which has long served as a passage for ships. So long ago as 1484 (1480?) the canal is said to have been destroyed by a storm, as has since happened on several occasions; under the English government it has been deepened. The friable calcareous sandstone of the

[1] R. Bruce Foote, On the Geology of South Travancore, Rec. Geol. Surv. India, 1883, XVI, p. 30; On the Geology of the Madura and Tinnevelley District, Mem. Geol. Surv. India, 1883, XX, pp. 46 and 55–74, map; Lieut. Christopher, Accounts of Adam's Bridge, Trans. Bombay Geogr. Soc., 1846, VII, pp. 130–133; B. R. Branfill, Physiographical Notes on Tanjore, &c., Journ. Asiat. Soc. Bengal, 1878, XLVII, 2, p. 187.

[2] F. von Richthofen, Bemerkungen über Ceylon, Zeitschr. deutsch. geol. Ges., 1860, XII, p. 529; also Schlagintweit, Reise in Indien und Hochasien, 1869, I, p. 147 (elevation of the whole of Hindustan).

bar breaks up into great rectangular blocks, and this no doubt gave rise to the belief that it is a colossal causeway of artificial construction. From Rameswaram the mound curves to the south-east; at first it is a sandy spit sixteen kilometers in length, very flat and at the time of the south-east monsoon partly submerged. Then a gap begins and continues for thirty kilometers, but troubled by many banks of shifting sand; on this follows a broader bend which almost reaches the island of Ceylon. Everywhere it presents the same friable calcareous sandstone. This bar is the scene of one of the most beautiful episodes in the great epic of Rámáyana.

The hero Rama, accompanied by his true-hearted spouse Sita, endures many years of exile in the woods and deserts of southern India. Then Sita is carried off by Rávana, the king of Lanka (Ceylon). Rama goes forth to wage war against Lanka and to recover his faithful wife; he will throw a bridge across the sea; the 'people of the forest who have the form of apes and fight with trunks of trees and pieces of rock' are his numerous and mighty allies. The host encamps on the strand. Lost in contemplation, Rama with his army gaze on the vast ocean; disturbed and as though kindled by the wind the world of waters resembles the sea of air, and the air the Ocean; far away on the horizon heaven and sea merge into one another, the one adorned with stars, the other with pearls. For three nights the never yet conquered Rama lingers in deep meditation on the strand waiting until the god of the sea shall appear to him. Impatient, he seizes at last his bow, and shaking the earth as it were, looses flaming arrows like living fire into the abysses of the sea; so does Indra hurl his lightning. The waves rise like the mountains of Vindhya and the monsters of the deep fly terrified to the sea-god. The god appears; his colour is like the dark lazure stone, sparkling with gold. He speaks to Rama and says: 'It was thine ancestor Ságara who hollowed out for me my bed; therefore am I called Ságaride, the Lord of the Streams. I cannot suffer a bridge across my waters, lest others should see that I may be overcome. But if thou willest to throw up a dam, the ape Nala may construct it; neither the creatures of the deep nor storms shall hinder thee, and I will hold back the waves for thy sake and Nala's.'

The command is given and hundreds and thousands of strong apes begin the work. They tear up trees by their roots and throw them covered with blossom into the sea, and upon them bushes and creepers, and then great blocks of rock and again trees and then again rocks. So the dam is raised; Rama, his brother Lacsmana, and with them Sugriva, Hanumat and all the other doughty warriors of the army of apes, march over the dam to the decisive battle [1].

[1] Foote, On the Geology of South Travancore, Rec. Geol. Surv. India, 1883, XX, p. 74; Ramayana, Poema sanscritto di Valmici, tradutto per G. Gorresio, 8vo, Paris, 1856,

Thus, long before the beginning of our aera, the poet describes the origin of the bar. As long as the Ocean endures, he says, so long will this dam exist and the fame of Rama. Even at the present day a number of small isolated islands are called Nalasetu, i. e. the bridge of Nala; the nearest town of India is called Ramnad and its governor bears the title of Setupati, or governor of the bridge.

It is possible that some communication between the island and the mainland may have once existed, and have been afterwards destroyed by one of the mighty storms of the Indian Ocean; this might easily have happened independently of any change in the relative level of the strand. A broad band of recent alluvium derived from the mainland has been deposited against the north side of the bar. There is so much sand on this coast that the dunes cover it far and wide. On the recent alluvium an important river, the Vygah, is completely smothered up by its own sediments and does not again find its way to the light till it is close to the sea. The town of Ramnad stands on this same strip of alluvial land, which is evidently more recent than the western part of the bar between the mainland and the island of Rameswaram. The negative movement which left exposed the corals of Rameswaram as well as those of Ceylon had perhaps begun to make itself felt even before the formation of the existing bar.

The marine deposits of the littoral region were closely connected with a calcareous sandstone which has hitherto only furnished fossil wood, and which extends from here far to the north along the coast; this is the *Cuddalore sandstone*. In Trichinopoli, north of Madras, and north of the rapidly advancing delta of the Kistna we meet with shells of a brackish-water character in deposits many miles distant from the existing shore; a proof that the influence of the sea made itself felt far towards the interior. On the shores of lake Chilka in the district of Orissa (lat. 19° 40′ N.) beds of *Cytherea casta* and *Arca granosa* are to be seen twenty to thirty feet above high tide; neither species lives at present in the lake; *Cytherea casta* still lives in the estuary further down the valley [1].

Negative signs thus appear around the whole of the Indian peninsula; even the earlier observers perceived the magnitude of this phenomenon, and in 1850 Buist concluded that the whole of the northern hemisphere must have been affected by 'general vibrations [2].'

IX, lib. v, Sundaracanda, pp. 132, 141, 185–192; for the distinction between causeway and bridge, p. 362, note 91. Here I am indebted to Professor Bühler for kind information.

[1] H. F. Blanford, Mem. Geol. Soc. India, 1862, IV, p. 19; Foote, On the Geological Structure of the East Coast from lat. 15° N. to Masulipatam, op. cit., 1879, XVI, p. 92 et seq.; Schlagintweit, Zeitschr. f. allg. Erdk., alte Reihe, V, p. 163; W. T. Blanford, Geological Structure and Physical Features of the Districts of Bancoorah, Midnapore, and Orissa, Bengal, Mem. Geol. Surv. India, 1859, I, p. 275, and Sketch of the Geology of Orissa, Rec. Geol. Surv. India, 1872, V, pp. 59, 61 et seq. Neumayr quotes *Arca granosa* in fresh water from Yang-tse-kiang; Neu. Jahrb. Min., 1883 b, p. 22.

[2] G. Buist, On the general Vibration or Descent and Upheaval which seems at a recent

On the east coast of the gulf of Bengal the negative signs reappear. Apart from contradictory accounts relating to the immediate neighbourhood of the mud volcanos, we find on the west coast of *Cheduba* a littoral formation and Pholas borings at a height of + 20 feet, and according to Richthofen various signs of negative movement occur at *Maulmein*. On the volcanos of Barren island and Narcondam nothing similar is to be seen, but on the coasts of the southern *Andaman* islands, according to R. D. Oldham, relict strand-lines are clearly marked. Notwithstanding this, the same observer remarks that no perceptible displacement of the strand has occurred since the time when the kitchen middens near port Mouat began to accumulate, that is during a period which must be measured by hundreds, perhaps even thousands of years [1].

On some of the *Nicobar* islands exposed coral reefs may be seen; Rink describes one on Bambuca; the negative movement must have amounted to at least sixty feet; towards the sea the reef terminates in a steep cliff; its foot is fringed by a living reef [2].

On the other hand the accounts at my disposal with regard to the coasts of Sumatra are very doubtful [3]. For *Java* they are much more definite, but here the negative movement did not exceed + 10 or at most 15 meters. Junghuhn has collected all the data referring to the south coast, but the displacement in post-Tertiary times is estimated at not more than twenty to twenty-five feet. For the exposed reef of Tji-Laut-urun (II, p. 320) Richthofen gives a height of + 40 feet. On the east coast Stöhr mentions a recent coral reef at a height of + 15 meters [4]. Further east it

geological Period to have occurred all over the Northern Hemisphere; Journ. Asiat. Soc. Bengal, 1850, XIX, p. 300.

[1] F. von Richthofen, Zeitschr. deutsch. geol. Ges., 1862, XIV, p. 367; F. R. Mallet, The Mud Volcanos of Rámri and Cheduba, Rec. Geol. Surv. India, 1878, XI, p. 190; The Volcanos of Barren Island and Narcondam, Mem. Geol. Surv. India, 1885, XXI, 4, p. 15 (the supposed traces of recent elevation in Barren island are not really such); R. D. Oldham, Notes on the Geology of the Andaman Islands, Rec. Geol. Surv. India, 1885, XVIII, pp. 143–145.

[2] H. Rink, Die Nikobarischen Inseln, 8vo, Kopenhagen, 1847, pp. 82, 109; F. von Hochstetter, Beiträge zur Geologie und physischen Geographie der Nikobar-Inseln: Reise S. M. Fregatte *Novara*, 4to, Vienna, 1866, II, p. 98.

[3] Wherever the Tertiary formation has been studied in detail, as in the island of Nias, no elevated coral beds are mentioned; e. g. Verbeek, Jaarb. Mijnw. Ned. O. Ind., 1876, IV, 1, p. 13. But according to Jack, Darwin has quoted them from Nias; Coral Reefs, p. 178.

[4] Junghuhn, Java, 8vo, Leiden, 1850, II, 2, pp. 1436–1448; E. Stöhr, Het rijzen der oostkust van Java, Natuurk. Tidschr. v. Nederl. Ind., 1867, XXIX, pp. 76–81; J. Hageman, Over het rijzen der kusten van Oostelijk Java en Madoera, op. cit., 1868, XXX, pp. 248–284; Richthofen, Ueber Mendola-Dolomit, etc., Zeitschr. deutsch. geol. Ges., 1874, XXVI, pp. 239–250; Stöhr, Die Provinz Banjuwangi in Ost-Java, Abh. Senckenb. naturf. Ges., 1874, IX, p. 49 et seq. On the upper course of the Serajoe river in the Dieng mountains, Edeling has described terraces which he compares to the parallel roads of Lochaber; Staring has shown that they are the result of repeated landslips which blocked the river; Edeling, Natuurk. Tidschr. v. Nederl. Ind., 1865, XXVIII, p. 395; W. C. H. Staring,

becomes more and more difficult to determine which of the numerous observations refer to Tertiary, which to Quaternary or even more recent formations, since there is scarcely any indication of the age of these deposits after we pass the Miocene period. This is particularly true of the accounts relating to *Borneo*, *Celebes*, and the *Banda* islands. Even in the case of the Mediterranean it is scarcely possible in the present state of our knowledge to arrive at any definite conclusions as to the precise horizon which corresponds to the high-level shell-beds of Sweden; the difficulties are still greater in the West Indies, where, as in the Mediterranean, traces of negative movement are visible one above the other, reaching back into the Tertiary area; here, where exact investigation has scarcely commenced, and the Tertiary beds similarly occur, we cannot venture at present to draw any conclusions[1]. It has been stated, for instance, that *Aaru* is a great exposed platform with mountains formed of late Tertiary beds rising from it; but we neither know the exact age of these beds nor can we tell where to place the recent platform among the many phases which, as Europe shows us, have succeeded each other since the close of the Tertiary aera. It is certain that at many places exposed coral beds occur here and also submerged forests, produced, as in so many other cases, by a sliding down of the coast land. Thus Junghuhn states that in 1820, probably during the long-continued eruptions of the adjacent volcano of Apea, a fragment of the little island of Wai, which forms one of the Banda group, sank so far that the tops of the trees growing upon it did not reach the level of the ground which had remained standing[2].

Formations indicating negative movement are continued towards the north; it will suffice to refer to the works published by Drasche and Montano on the Philippines and by Richthofen on Formosa. But I see no means of determining the age of these formations; nor is it possible to make any definite statement with regard to the height of the beds, since some observers have certainly included Tertiary limestones among them[3].

With regard to *Siam* we have no information; the account of Pallegoix adduced in proof of an elevation of the land refers, according to his own

Over oude meer-oeverbanken op Java, Versl. en Mededeel. Akad. Amsterdam: Afd. Natuurk., 1866, 2. R., I, pp. 345–348.

[1] Information as to this region will be found in Reinwardt, Poggendorff's Ann., 1824, II, p. 444; A. R. Wallace, On the Physical Geography of the Malay Archipelago, Journ. Roy. Geogr. Soc., 1863, XXXIII, pp. 222 et seq.; A. S. Bickmore, Reisen im Ostindischen Archipel, translated into German by Martin, 8vo, Jena, 1869, pp. 71, 185, 288, 388. Dr. A. B. Meyer, of Dresden, has had the kindness to send me his observations on north Celebes.

[2] Junghuhn, Java, II, 2, p. 1435.

[3] Cuming, in Darwin, Coral Reefs, p. 178; von Drasche, Luzon, pp. 9, 47, 61 et passim; Montano, Arch. des Miss. scient., 1885, XI, p. 271 (elevation of the east coast of Mindanao and of the gulf of Davao); Richthofen, Zeitschr. deutsch. geol. Ges., 1860, XII, pp. 539, 545.

statement, to the formation of land by silting up. The structure of the alluvial land on the lower Mekong (II, p. 170) shows that no important change has taken place in recent times. Bastian, however, mentions that Schomburgk encountered specimens of existing marine shells at a height of + 60 feet close to Anghin on the lower Menam in the interior of the country. According to Ratte, Bocourt found at a considerable height above Bangkok marine shells, in particular *Arca granosa*, associated with species which occur at the mouth of the river, and the Abbé Montrouzier is said to have observed marine deposits containing recent shells at some distance from the sea. Whether in some cases these observations may have been made on kitchen middens it is scarcely possible to say [1].

With the exception of the regions just mentioned which are little known, the whole coasts of India and Further India clearly reveal along their whole course an originally higher level of the strand-line. This is particularly true of the Indian peninsula, where a Tertiary border is absent; in the immediate proximity of cape Comorin marine post-Tertiary deposits occur at a height of + 48·5 meters. Further east the traces of negative movement still continue, even as far as the Philippines and Formosa, but in these eastern regions and particularly around the sea of Banda a Tertiary border is everywhere present and the precise age of the several beds is unknown.

5. *Coasts of the Polynesian islands and Australia.* All that has been said of the islands of the sea of Banda is equally true of *New Guinea*. Numerous traces of negative movement are to be seen, but the recent deposits have not been clearly distinguished from those of Quaternary or Tertiary age. Wallace, who spent three months on Dorey, in the north of New Guinea, states that this long and low promontory is entirely formed by a recent coral reef, and that coral reefs occur up to a height of + 200 or 300 feet without any perceptible change in their structure. In Fergusson island, close to the south-east coast, Moresby saw great masses of coral reef adjacent to the volcanic rock, about 100 feet above the sea [2].

These negative indications are continued on the adjacent islands, as may be shown by a few examples :—

In Catharine bay, *New Ireland* (lat. 3° 11′ S.), the coast, according to

[1] Pallegoix, Description du royaume Thai ou Siam, 8vo, Paris, 1854, I, p. 115; A. Bastian, Die Hydrographie Hinterindiens, Peterm. Mitth., 1866, XII, p. 457; F. Ratte, Notes sur l'Indo-Chine, Bull. Soc. géol. de Fr., 1876, 3e sér., IV, p. 519.

[2] A. R. Wallace, Notes on a Voyage to New Guinea, Journ. Roy. Geogr. Soc., 1860, XXX, p. 173; J. Moresby, Discoveries in Eastern New Guinea, op. cit., 1875, XLV, p. 156. Miklouho-Maclay says that on the Maclay coast marine shells occur in greenish clay; Wilkinson compares the clay with the Tertiary clay of Yule island; according to Brazier, however, only living species occur in the latter; N. de Miklouho-Maclay, Evidences of the Rising of the Maclay Coast in New Guinea, Proc. Linn. Soc. N.S.W., Sidney, 1885, IX, p. 956 et seq. At Anuapata, New Guinea, mollusca, 'similar to the existing mollusca,' are said to occur at a height of 600 feet; Stone, Proc. Roy. Geogr. Soc., 1876, XX, p. 331.

Schleinitz, descends in many places sheer into the sea from a height of ten to twenty meters. Cavities hollowed out by the sea may be clearly seen about five to eight meters above the existing sea-level, and we 'probably have here, as in New Hanover and the western parts of New Ireland, an elevated coral reef, although the colour and structure of the rock, so far as can be recognized from some distance off, point rather to sandstone.' The strand-lines on the *Solomon islands* have already been mentioned (II, p. 315). In the *New Hebrides*, according to Hosken, negative indications may be seen on almost every island. Around Tanna a relict strand-line lies fifteen to thirty feet above high tide, and the cliffs are frequently undercut. Along the south coast of Erromango five distinct terraces extend as far as the eye can reach; Sandwich island ascends in terraces to the foot of the volcanic mountains of the interior; Deception, Hat, Lopevi, Star peak, Mota and Saddle islands show similar features; the lowest terrace on the island corresponds to the flat country of the coast. Pentecoste does not exhibit the terraces so clearly, but ancient coral rock is met with fairly high up towards the interior of the island. The great terraces of the *Loyalty* islands have already been mentioned, as well as the presence of marine Tertiary beds in *Viti Levu*. The western *Tonga* islands, according to Schleinitz, are all of a tabular form, covered with vegetation, and present steep sides which are undercut at the sea-level [1].

The fragments of table-land, the terraces, and strand-lines thus extend from the sea of Banda and New Guinea to those isolated tabular blocks, surrounded by a barrier reef and a lagoon, which are met with here and there in the midst of the Pacific Ocean, as far as the remote Henderson island. Far in the north, too, exposed coral reefs are to be seen in *Oahu*, and Honolulu is partly formed of coral rock [2]. Only very general oscillations of the strand-line could leave behind such extensive indications of their presence.

Let us again turn our attention to New Guinea.

Tenison Woods has examined the mollusca from the friable yellow limestone of *Yule island*, New Guinea, and describes them as more recent than the middle Miocene of South Australia, but still Tertiary; he points out how strange it is that evidence of elevation of the land is so frequent in New Guinea while absent from the east coast of Australia [3]. But here it must be remembered that the marine Tertiary deposits which extend from

[1] Captain von Schleinitz, Die Expedition S.M.S. *Gazelle*, Ann. d. Hydrographie, 1876, IV, p. 365; Lieut. Hosken, Remarks about the New Hebrides Group, Geol. Mag., 1876, 2nd Ser., III, p. 82.

[2] Cf. Coan's statement in Coral Reefs of Hawaii; Note in Am. Journ. Sci., 1874, 3rd Ser., VIII, p. 466.

[3] J. E. Tenison Woods, On a Tertiary Formation at New Guinea; Proc. Linn. Soc. N.S.W., 1878, II, pp. 125–128 and 267.

the south coast of Australia through Bass strait to the southern part of North Gippsland have yet never been encountered on the east coast of the Australian continent, nor on the east coast of Tasmania, and thus it seems probable that a recent fracture extends along the whole length of these coasts (II, p. 162).

The west coast of Australia, although as yet but little explored, has already yielded shell-beds at Fremantle (lat. 32° S.) which indicate negative movement. Their fauna is marked by tropical characters, and in this connexion it is interesting to observe that the existing fauna at Perth approaches the Indian rather than the Australian type [1].

The great development of barrier reefs which distinguishes New Guinea and the surrounding regions is also a well-known characteristic of the coasts of Australia. In the north-west the living coral reefs with their steep slopes extend as far as Ritchie reef, the northern end of which lies in lat. 20° 16′ S.; and on the east coast, Wide bay, north of Moreton bay, marks the entrance to the channel within the Great Barrier reef; the reef-building corals extend here somewhat south of lat. 28° S.[2] So far as these barrier reefs extend, both in the north and in the south, all negative movement at the present day is excluded; a movement in the opposite direction seems more probable. All the traces of negative movement which occur within the barrier reef are older than the reef itself. In north Australia, however, such traces are extremely rare; I know only of one instance, the occurrence of sea caves in sandstone above high-water mark observed by Rattray on Albany island in the extreme north-east. Insular formations consisting of piled up fragments of coral limestone, but not rising more than twenty feet above low water, such as form the island of Raine, for instance, cannot be regarded with certainty as indications of negative movement, especially in the light of what is known as to the height of the storm beaches on atolls [3]. Daintree states that no recent elevation of any importance is to be recognized on the coasts of Queensland [4].

In the south, wherever Tertiary deposits are present, we also have accounts of comparatively recent negative movements. With regard to Gippsland, observers agree in stating that at some late period, which is termed Pliocene, the sea extended over a large part of the colony, reaching according to Howitt a height of 800, according to Murray of 900 feet, and

[1] J. E. Tenison Woods, On the extra-tropical Corals of Australia, Proc. Linn. Soc. N.S.W., 1870, II, p. 296.

[2] Hydrographical Notice, 1879, No. 14, Ann. d. Hydrographie, 1880, VIII, p. 156. Elizabeth reef, 90 sea miles NNW. of Lord Howe island, lat. 29° 56′ S., is an atoll with a lagoon; Hydrographical Notice, 1878, No. 20, Ann. d. Hydrographie, 1878, VI, pp. 424–426.

[3] A. Rattray, Geology of Cape York Peninsula; Quart. Journ. Geol. Soc., 1869, XXV, pp. 298, 303.

[4] Daintree, Quart. Journ. Geol. Soc., 1872, XXVIII, p. 273.

further, that since then the land has been laid dry by repeated oscillatory movements which possibly still continue at the present day. The negative indications in Victoria are so striking as to have impressed Brough Smyth with the belief that the whole Australian continent is experiencing a tilting movement, such as was supposed at that time to be also taking place in Scandinavia and Greenland; he thought that the south was rising and the north sinking about a neutral axis situated somewhere near latitude 30° S. Wood has collected many accounts of the strand-lines and terraces of the south; Rawlinson describes three stages one above the other on the coast of the western district of Victoria, and a fourth is probably in process of formation [1].

When Hochstetter, in 1859, made his observations on the terraces and recent littoral deposits of *New Zealand*, he was astonished at their resemblance to those of Europe. 'We must admit,' he wrote in 1864, 'that the complete concordance of the successive elevations and depressions, recognized on both sides of the Atlantic, with the post-Tertiary movements in New Zealand, is a fact remarkable and surprising in the highest degree, such as cannot fail to give rise to manifold conjectures [2].'

The description given by Cox of the inland terraces around lake Te Anau, and that by McKay of the coast terraces of the east Wairarapa district, testify to the resemblance of these terraces with those of Norway [3].

It is not necessary, however, to cite the numerous individual observations, since they have been collated by Hutton in a general survey. According to this author we find, as we proceed from north to south, the following:—(i) on the river Thames, near Auckland, a seashore with shells at a height of + 10 to 12 feet; (ii) below the town of Tauranga, at a height of about + 25 feet; (iii) at Taranáki, beds with recent shells at a height of 150 feet; (iv) littoral terraces at the mouth of Cook strait at a height of more than 200 feet; (v) on the west coast of the South island comparatively recent terraces at a height of 220 feet, according to another statement up to 400 feet; (vi) at Amúri bluff three terraces with recent shells at a height

[1] Howitt, Quart. Journ. Geol. Soc., 1879, XXXV, p. 34; R. A. F. Murray, Geological Survey of Gippsland, Russell's Creek Goldfield, Rep. Geol. Surv. Victoria, 1880, VI, pp. 39–47; R. Brough Smyth, The Gold Fields and Mineral Districts of Victoria, 8vo, Melbourne, 1869, p. 11; J. E. Woods, Geological Observations in South Australia, 8vo, London, 1862, p. 205 et seq.; T. E. Rawlinson, Notes on the Coast-Line Formation of the West Districts and Proofs of the Uniform Conditions of Meteorological Phenomena over Long Periods of Time, Trans. Proc. Roy. Soc. Victoria, 1878, XIV, pp. 25–34 (between Warnembool and Belfast).

[2] F. von Hochstetter, Reise der österreichischen Fregatte *Novara*, 4to, Wien, 1864; Geologischer Theil, I, p. 265.

[3] S. H. Cox, Report on the Geology of the Te Anau District, Geol. Surv. New Zealand, 1877–1878, Wellington, 1878, p. 118; A. McKay, The Southern Part of East Wairapa District, op. cit., 1878–1879, p. 85; Crawford, (Cook strait,) Trans. Proc. N. Z. Inst., 1884, XVII, p. 342.

of 500 feet; (vii) in north Canterbury marine shells up to 150 feet; (viii) fine mud with isolated marine shells at a height of 800 feet on Banks peninsula, and (ix) at 500 to 600 feet at Oamarú. On the south-west coast the mouths of the fjords are terraced as in Scandinavia up to a height of about 800 feet. In the most northerly part of New Zealand, the height at which such terraces are known to occur is but slight; towards the south it increases considerably.

Hutton had previously shown that the fauna of these shell-beds is very closely allied with that of the present day. New Zealand extends from lat. 34° to 47° S. and the existing mollusca of its north coast are altogether different from those of the south coast. In Cook strait the forms are intermingled, with a predominance of the northern species, i. e. those inhabiting the warmer seas. The extensive shell-beds of Wanganui, Cook strait, which are described as 'Pleistocene,' have yielded ninety-one species, of which eighty-one are known to occur in the existing seas of New Zealand; fifteen of these species appear to be absent from the coasts of Otágo, but it is probable that they still exist in Cook strait. On the other hand these shell-beds contain *Pecten radiatus*, a species which only exists at present in Foveaux strait, and may be regarded as an immigrant from a colder region. Beneath the shell-beds there lies blue clay regarded as 'Pliocene,' with ninety-eight species of mollusca, of which only seventy-seven live in the New Zealand seas; among the species which still exist are many from the north, but with them the same *Pecten radiatus* and the little *Drillia laevis* of Foveaux strait, which is so small that if it occurs further north it may easily have been overlooked [1].

In considering the coasts of Australia and Polynesia we must leave out of account the east coasts of Australia and Tasmania, which appear for many reasons to be a fractured margin of recent age presenting no indications of negative movement. With this exception such indications are everywhere present, often even within the barrier reefs. In many cases they extend from New Guinea through the groups of islands to Henderson and Oahu. If with Darwin we regard the living coral reefs as a proof of positive movement, then we must admit that this is everywhere more recent than the signs of negative movement. On the south coast of Australia, particularly in Victoria, these negative indications are much more important, and attain greater heights than on the shores of warmer seas; it has been definitely shown that in New Zealand a considerable increase of elevation takes place as we approach the south.

6. *West coast of South America.* In the volcanic group of the *Galápagos* the islands are separated from one another by considerable depths.

[1] F. W. Hutton, Sketch of the Geology of New Zealand, Quart. Journ. Geol. Soc., 1885, XLI, p. 212; Did the Cold of the Glacial Epoch extend over the Southern Hemisphere? Geol. Mag., 1875, dec. 2, II, pp. 580–583.

Pourtalès has observed several species of reef-building corals as far as the southernmost island and beyond the region of the warm current; they were always found to occur, however, as loose fragments, although the possibility of drifting from a distance is almost excluded. T. Wolf emphatically denies the existence of all signs of elevation of these islands, i. e. of any negative movement [1].

On the coast of *Ecuador* and as far as Peru the sea, according to Wolf, has cut a plain of erosion in the sandstone 10 to 100 meters broad, which serves as a natural road for long distances and renders it possible, at the time of lowest ebb, to walk around the steep promontories. We have already mentioned that Bibra, David Forbes, and Darwin himself, observed ancient graves and buildings on the west coast of South America, so near to the sea that no important change can have affected the strand-line in this region for many centuries; Wolf's statements relating to Ecuador confirm this view as applied to the regions lying further north. A letter received from this enthusiastic observer informs me that on the peninsula of Santa Elena, province of *Guayaquil*, there are deposits containing marine shells of existing species, and bones of *Mastodon Andium*. Thus indications of negative movements in earlier times are not wanting [2].

Further south, throughout Peru, Chili, and as far as the southern extremity of the continent, signs of negative movement, and particularly terraces, present so striking an appearance that they have attracted the attention of observers for many years past. The distinct terracing both in the east and west of South America led Darwin to the conclusion that the whole continent from the south up to about lat. 30° S. was undergoing an intermittent elevation, and he attempted as early as 1838, following the views and observations of that time, to find some original connexion between the volcanos, the earthquakes, and the terraces of South America (II, p. 15). A. d'Orbigny concluded in 1843 that these terraces afford evidence of a spasmodic elevation affecting the whole continent, just as Kjerulf did later in the case of Norway. In 1848 Domeyko also recognized the great similarity between these terraces and those of Norway, and concluded from it that the causes of the phenomenon must have been active simultaneously in both hemispheres (II, p. 17) [3].

[1] Pourtalès, Corals of the Galápagos Isles, Am. Journ. Sci., 1875, 3rd Ser., X, p. 282; T. Wolf, Zeitschr. f. d. ges. Naturw., 1880, LIII, p. 281.

[2] T. Wolf, tom. cit., pp. 282 et seq. J. S. Wilson believed he had seen several low-level terraces at the mouth of the river Esmeralda; they are said to contain traces of human occupation below high-water level, and from this he inferred a recent subsidence of the land; this observation, however, is regarded as doubtful; Quart. Journ. Geol. Soc., 1866, XXII, pp. 567–570. Cf. also Zeitschr. deutsch. geol. Ges., 1877, XXIX, pp. 412–415.

[3] C. Darwin, On the Connexion of certain Volcanic Phenomena in South America (read 1838), Trans. Geol. Soc., 1840, V, pp. 505–510; A. d'Orbigny, Compt. rend., 1843, XVII,

It is particularly difficult to form any opinion on this question. Permanent elevation of coastal regions originating simultaneously with earthquakes has not been proved (I, p. 95). The presence of marine amphipods in lake Titicaca, the discovery of corals having a very recent appearance at heights of from 2,900 to 3,000 feet, and the existence of salt lagoons at between 7,000 and 12,500 feet have been adduced as so many proofs of an extremely recent elevation, but the objections to this conclusion have already been urged (I, p. 540). All these questions may be regarded as definitely disposed of, and we will now devote ourselves exclusively to a closer consideration of the terraced land.

The first difficulty which confronts us here is the presence of inland terraces and marine terraces in the same region. The Huaraz and the upper Marañon are bordered by river terraces, as are all the numerous rivers which descend from the Andes; from Chiloé onwards the country apparently reproduces all the most important features of the Norwegian coast. The great ranges lie so near the sea that in many cases their débris extends down to the shore; and the numerous observations of travellers on the terraced land do not always enable us to discover whether they refer to true strand-lines of the sea, or to the lower stages of those inland terraces, which may be traced far up the river valleys.

On other coasts the presence of sea-shells has furnished us with a criterion on this point. But this also must be used with caution, on the one hand because, as David Forbes remarks, sea-shells are carried up to heights by birds, a circumstance also pointed out by Steenstrup and Nordenskiöld in the north, and on the other hand because it is precisely here, and more particularly in the south, that kitchen middens occur on a large scale. Marine animals, and especially shell-fish, still form the staple food of many coastal tribes in the south-west of America. On the coast of Llanquihue in south Chili, as Captain Gormaz relates, crowds of women go down to the sea, towards the time of low tide, provided with pointed sticks and baskets.

At once the sea-birds flock together, uttering shrill cries. The house-dogs and pigs, frequently even the domestic fowl, come down to gather the food which is offered so liberally by the sea. In some islands, such as Chiloé and Nao, the pigs are employed, like truffle-dogs, to look for bivalves buried in the sand. The men, however, only take part in this work just before the times of the solstices and equinoxes, which are well known to them, with a view to providing a store for use during storms; this they do by making artificial beds of shells at the level of neap tides. A bed of bivalve shells, covered thickly with vegetation, borders the strand north of

p. 401; Domeyko, Mémoire sur le terrain tertiaire et les lignes d'ancien niveau de l'Océan du Sud aux environs de Coquimbo, Chili, Ann. des Mines, 1848, 4e sér., XIV, pp. 153–162.

Coihuin, not far from Puerto Montt, at a height of about five meters above the sea; this consists chiefly of the shells of *Venus cineracea*, a species which still forms the daily food of the population, and it must certainly be regarded as an artificial accumulation [1].

Such stores of food are called *cholcheñ*. In Possession bay, Patagonia, L. Agassiz came across a brine pool at a height of nearly 150 feet above the sea; its saltness was more than twice as great as that of sea-water, and its depth in the rainy season from three to four feet. It contained marine shell-fish, both living and dead. Agassiz concluded that at a very recent period, i. e. within the lifetime of these animals, the land must have risen 150 feet. It seems to me, however, much more probable that the pool was a cholcheñ, notwithstanding its height above the sea [2].

The inhabitants of Chiloé, according to Fonck, carry these shell-fish far into the interior. In 1854, when some Germans who had settled on the neighbouring continent for the first time visited the shores of lake Llanquihue, the country was covered for many miles around by a dense forest. Yet they found kitchen middens of this kind, together with iron implements, clay vessels, and other objects, beneath overgrown ground at a height of 300 feet above the sea or even more. We know, however, that in 1638 a large part of the native population was carried off by an epidemic, and Fonck conjectures that the remainder fled into the interior of the country. Thus the age of the forest, now covering the ancient settlements, cannot be more than two or three hundred years [3].

In all cases where these kitchen middens occur in a somewhat severe climate, whether in south Chili, Oregon, or even Greenland, their site is marked by luxuriant vegetation due to the presence of fertilizing refuse. It cannot be denied that a number of the shell-beds cited by Darwin are of artificial origin. Darwin felt this himself and did not conceal his doubts. As proof we may mention the bed of Venus and oysters which he observed in Chili at a height of 350 feet in a black peat-like earth, covered by lofty forest; beneath it he found the horn of a deer, *Cervus humilis*. The black earth itself in which the shells are found in so many localities, especially near Valparaiso, does not resemble a marine deposit; when crumbled between the fingers it emits an evil odour recalling a mixture of soil and guano, and its general character is that of a terrestrial soil. So careful an observer as Darwin could not even at that early period overlook these facts, but since a microscopic investigation of the earth revealed the presence of numerous small fragmentary remains of marine animals his suspicions were

[1] Capt. Gormaz, Esploracion de la costa de Llanquihé, An. Univ. Chile, 1872, XLI, pp. 235, 253, 361; Mem. de la marina de Chile, 1872, pp. 203 et seq.

[2] L. Agassiz, Nature, 1872, VI, p. 229 (in the New York Tribune).

[3] F. Fonck, Naturwissenschaftliche Notizen über das südliche Chile; Peterm. Mitth., 1866, XII, p. 467.

allayed. This fact has not, however, the importance Darwin attributed to it [1].

When we have really succeeded in distinguishing inland terraces from marine, and kitchen middens from shell-beds formed by the sea, we find ourselves confronted by a fresh difficulty, as yet by no means overcome; this consists in the different age of the shell-beds, the determination of which is associated on this coast with questions of a peculiar nature.

On the south-east coast of America, the Tertiary formations of Patagonia extend in horizontal beds for more than twenty degrees of latitude, maintaining the same characters from their boundary in the south up to the basin of the Paraná in the north; marine deposits alternate with terrestrial. According to Doering's observations we have first a lower marine stage, perhaps of Eocene age (*Piso Paranense*), then terrestrial deposits which contain some mammalian remains resembling those of the Oligocene fauna of Europe; above this a second marine stage, perhaps of the upper Oligocene (*Piso Patagonies*), then come the latest Tertiary deposits found in this region, which are all terrestrial. Next follows an interval which corresponds to a period of denudation, and this finally is succeeded by the post-Tertiary or quer-Andinian marine stage, the deposits of which ascend higher and higher towards the south above the existing sea-level (II, p. 307).

This series of deposits reveals oscillations of the strand-line of extreme regularity extending over a long period. The existence of successive terraces on the west coast would lead us to infer that similar phenomena had occurred there within the limits of the Tertiary aera. But whereas in the east there is an extensive plain of Tertiary sediments built up in alternate series and extending far beyond the Pampas, in the west, on the other hand, only small patches occur scattered in various latitudes and separated from each other by wide intervals.

In the existing seas the mollusca of the west coast of South America differ completely from those of the east and from those of the Atlantic generally. The south end of the continent now forms a definite boundary. Nevertheless Alcide d'Orbigny found a species, *Trochus collaris*, at Navidad in Chili (lat. 33° 54′ S.), which belongs to the Patagonian Tertiary of the east; some years later Sowerby identified in Darwin's collection from Navidad five or six species which also occur in the Tertiary beds of the east; and this number has been raised to nine or ten by Philippi's investigations.

[1] C. Darwin, Geological Observations, 2nd ed., 1876, pp. 234, 242. Hahn shares Darwin's doubts with regard to Chiloé; Hahn, Untersuchungen über das Aufsteigen und Sinken der Küsten, p. 91. P. Germain even believes that all the shell-beds mentioned by Darwin in this region are nothing but kitchen middens; Germain, Observations sur les mouvements du sol dans l'archipel de Chiloé, Compt. rend., 1883, XCVI, pp. 1806–1808. The kitchen middens are also described by D. Lovisato; Appunti etnografici con acc. geologici sulla terra di Fuoco, Cosmos, edited by G. Cora, VIII, p. 97 et seq.

While studying this western Tertiary deposit, however, Philippi, the undisputed authority on the fauna of the Mediterranean, arrived at a very remarkable result, for he found *that the Tertiary mollusca of Chili present a greater resemblance to those of the Mediterranean than to those now living off the coast of Chili.* Chenopus, Conus, Terebra, Cassis, Cypraea, Solarium, Thracia, Corbula, and many other genera which distinguish the Atlantic region and particularly the Mediterranean sea and its Tertiary deposits, are present in the Tertiary of Chili, but absent from its existing seas [1].

Thus isolated, this fact may appear extremely strange, but it is connected with a series of observations which have already engaged our attention. We have seen that the marine Trias while surrounding the Pacific Ocean maintains a uniform character, in Chili the Jurassic presents itself with European characters, so does the lower Cretaceous in Bogotá, and the middle Cretaceous in Jamaica; in the Tertiary deposits of the West Indies the Oligocene corals of Castel Gomberto occur, and the Orbitoides limestone marks, there as in Malta, the base of the Miocene; and finally even the first Mediterranean stage of Europe is indicated in the same region by certain Echinoids. These are the traces of the ancient central Mediterranean which, during the Mesozoic and lower Tertiary aera, extended parallel with the equator; and the European stamp borne by the Tertiary deposits of Chili shows that the isolation of this region did not take place until comparatively recent times, probably about the middle or towards the end of the Tertiary aera. It was Philippi who, more than half a century ago, laid the foundations of our knowledge concerning the Tertiary faunas of the Mediterranean; he showed how the northern immigrants made their appearance as the forms of a warmer climate retreated, and that the existing fauna of the Mediterranean is the most recent term of a series of antecedent faunas. His work has served as a starting-point for those various investigations which have slowly and gradually revealed the history of the Mediterranean in its main outlines. After a lapse of many years the opportunity was afforded him of applying his observations in the Mediterranean to a study of the succession in Chili; but in this case he arrived at a very unexpected result. Instead of a serial succession of allied faunas closing with the existing fauna as its last term, he found first a fauna of Mediterranean affinities, then a complete change of character; the Mediterranean fauna disappears and its place is taken by a younger fauna, described as Quaternary, and this, though imperfectly known, is evidently identical in its general characters with that of the coast of Chili at the present day; finally the existing fauna completes the series.

In Europe the prevalence of a cold climate is regarded as marking the

[1] R. A. Philippi, Die tertiären und quartären Versteinerungen Chile's, 4to, Leipzig, 1887, p. 257.

Quaternary period. The gradual manner in which the northern species increase in number in the English Crag renders it improbable that this period commenced suddenly; we know that great alternations of temperature occurred, and that the last negative movements are more recent than the culmination of the glacial episode. The succession of the marine faunas in Chili is characterized by an event of quite another kind, that is, the disappearance of the fauna possessing a European character. As to the cause of this disappearance we are at present very much in the dark; it may have been due to a negative displacement of the strand-line and consequent isolation of the west coast, or possibly to the closure of the isthmus of Panama by volcanic eruptions, or it may perhaps have resulted from the first appearance of the cold Humboldt current, which at present follows the west coast, or some other circumstance may have been involved; possibly indeed it was the conjoint effect of more than one cause. It is not impossible that this event may have actually coincided with the incoming of the glacial epoch, but we have no evidence on this point, and thus it remains an open question whether the terms Tertiary and Quaternary as applied in Chili really possess the same significance as in Europe.

It is evident, under these circumstances, that the method of determining the relative age of deposits by the percentage of living species does not hold here, for all those sediments, which were anterior to the phase marked by the disappearance of the European types, contain so small a number of existing Chilian species that they must by this criterion be assigned to the Eocene. This in fact is the position accorded them both by Sowerby and Philippi. The comprehensive works of Philippi give for the living forms found in the Tertiary deposits the following results: at Coquimbo, which has furnished 89 species, only 2·5 per cent., at Navidad (291 species) 1 per cent., at Levu (153 species) 1·5 per cent. Thus at the present day the ancient character has completely disappeared. But no exact determination of age can be based on these facts.

On the east coast of Patagonia the intercalated terrestrial faunas afford material for a classification nearly approaching that of Europe; assuming of course that terrestrial faunas which contain representative species of the European are really synchronous with the latter. In Chili we do not possess the means of determination; not unimportant differences distinguish the marine Tertiary faunas of different localities, as is the case with the existing marine faunas in different latitudes. Of the 89 Tertiary species occurring at Coquimbo and Guayacan (lat. 30° S.) only 7 to 10 occur at more southerly points of the west coast, and we can hardly say whether this is due to a difference in climate or age, or to some other circumstance. On the other hand Philippi lays stress on the fact that the deposits at Santa Cruz, Patagonia (lat. 50° S.), closely resemble those of the east coast, as well as those of Navidad on the west coast (lat. 33° 54′ S.). The

species in common appear to me to definitely indicate Doering's *Piso Patagonies*, which is doubtfully assigned to the upper Oligocene.

I am not aware of any attempt so far to discover an equivalent of the European Miocene or Pliocene on the coast of Chili or Peru.

Now at length, after these various discussions on the earthquakes of Chili, the irrelevance of inland terraces and kitchen middens, as well as the significance of the terms Tertiary and Quaternary as applied to Chili, we may venture to consider more closely some particular localities along this extensive line of coast.

Between Mejillones and Autofagasta (lat. 23° to 23° 33′ S.) an independent segment of the littoral cordillera running north and south forms a prominent feature of the coast. In the north it rises into the Morro de Mejillones (885 meters) and in the south into the Morro Morena (1,250 meters); a belt of land not more than 60 or 70 meters in height unites this mountain fragment with the mainland, or more precisely with the Cerro Gordo, the most westerly range of the cordillera. Some of the channels eroded in the flanks of the Morro de Mejillones contain considerable quantities of guano, and under the guano, on the lower slopes, Wilhelm Krull has observed at various altitudes the relics of the ancient shores, consisting of horizontal beds of sand with marine shells and rolled pebbles, which sometimes form a discontinuous terrace [1]. At my request Herr Krull has been good enough to investigate all the traces of ancient strand-lines on the Morro and to determine their height. I extract the following from communications he has been so kind as to send me.

The Morro de Mejillones is a granite mass elongated meridionally; seen from either north or south its outline is narrow and conical, but from west or east broad and dome-like. This rounded mass is surmounted by a broad ridge, elongated in the same direction, which descends in terraces, especially on its north-east and eastern sides; at its foot lies a broad plain some 200 feet above the level of the sea. It is in the ravines which furrow the Morro at a great height that the guano occurs, covered over by débris; a circular railway runs round the mountain just below the guano pits at a height of about 1,900 or 1,930 feet; out of one of the ravines about 70,000 tons of good guano was extracted. Below the railway the first indications of 'a periodic retreat of the sea or of an apparently spasmodic elevation of land are to be seen.' Krull distinguishes several zones or shore-lines at heights of 1,640 to 1,600, 1,430, 1,050 to 950, 730, 430, 360 to 350, 130 and 60 to 50 feet. Marine shells are said to occur up to a height of 1,430 feet

[1] Domeyko, Apuntes sobre el depósito de guano de Mejillones, sacad. d. l. cartas escritas por el Doct. Don Guill. Krull, etc., An. Univ. Chile, 1878, p. 449. At Miguel Diaz (lat. 24° 25′ S.) Philippi observed shells at a height of 280 meters: unfortunately they are lost; R. A. Philippi, Die sogenannte Wüste Atacama, Peterm. Mitth., 1856, II, p. 56.

(435 meters). On the lower slopes the deposits of guano are inconsiderable; at present guano is in process of formation at the northern point of the peninsula, quite low down at the sea-level.

Even if some of these successive strand-lines are not very sharply marked or definitely established, yet it is clear from Krull's observations that in this locality, where there are no inland terraces whatever, the strand-line once stood at a very high level, and was affected by a lengthy series of displacements with a negative preponderance; further, that the Morro was in all probability a guano island at the time the strand-line stood at its highest level. This accords with the fact that the avian remains found in the guano are probably, as Philippi is inclined to think, those of an extinct species.

Along the railway from Mejillones to the Cerro Gordo, the height of which is not far short of that of the Morro, Krull has found whole beds of shells. Philippi states that Vidal Gormaz obtained Quaternary shells from the Cerro Gordo at a height of 500 meters; these all belong to living species such as *Solen Dombeyi* and the little shells *Nucula Grayi* and *Cardita Semen*, three forms which are still found in the bay of Mejillones; with these, however, is *Cardium ringens*, which is at present foreign to the Pacific Ocean and *has its home on the coasts of Africa*[1]. This isolated but remarkable fact shows that the ancient beaches, which occur at a high level on the Morro and the Cerro Gordo, were formed at a period when the Atlantic fauna had not yet completely disappeared from the west coast.

Philippi also describes Quaternary shells from Mejillones, but without any closer indication of the locality; out of nineteen species only thirteen are still living, so that the proportion of extinct species is far higher than we are accustomed to find in Quaternary deposits.

The terraces of the *Caldera* near Copiapo (lat. 27° 4′ S.) and of Coquimbo (lat. 30° S.) have often been described. Remond states that on the Caldera they reach a height of 150 meters; of the mollusca they contain, Philippi has identified twenty-two living and two extinct species[2]. At Coquimbo the Quaternary sediments begin at a height of 60 meters; they rest on Tertiary beds and extend, according to Darwin, somewhat higher than in the surrounding country, namely to 300 or 350 feet (92·5 to 108 meters); Philippi describes forty-six living and eight extinct species from this locality.

Between the Caldera and Coquimbo lie the terraces which proceed from the transverse valley of the Huasco, and these, as shown by existing accounts, are of inland origin. The valley of the Huasco, like all the transverse valleys of this coast, rises steeply from the sea; the terraces, which extend as far as the shore, rise with it. As far as the town of Vallenar, that is, to

[1] R. A. Philippi, Die sogenannte Wüste Atacama; Peterm. Mitth., 1856, II, pp. 6 and 253.

[2] Remond, Apuntes sobre los terrenos terciarios i cuaternarios de Caldera i Coquimbo; An. Univ. Chile, XXXI, 1868, pp. 416–419.

a distance of about fifty-three kilometers inland, the breadth of the valley amounts to six or seven kilometers. Here, according to Mallard and Fuchs, the terraces surround the town like a great amphitheatre, sixteen to seventeen kilometers in diameter. Vallenar lies at a height of 513 meters; there are five successive terraces, the highest at a level of 650·4 meters. It is supposed that a fjord filled with débris must have extended nearly to the height of the uppermost stage; during the elevation of the land, running water produced one terrace after another. In connexion with this it must be observed that the uppermost terrace does not rest directly against the mountain, but is separated from it by a narrow valley, the bottom of which corresponds to the second terrace. Consequently this uppermost terrace is a spur, such as is not produced by the sea [1].

This does not imply that the strand did not once stand here at a very high level; even at Valparaiso (lat. 32° 2′ S.) Darwin observed shells up to 1,000 feet, and with somewhat less certainty even up to 1,300 feet (400 meters); in Cahuil (lat. 34° 29′ S.) a Quaternary bed at a height of only four or five meters contains, according to Philippi, five extinct along with thirteen living species.

The altitudes of all the terraces in Chili known up to the year 1860 have been tabulated by Domeyko, to whom our knowledge of this country is so largely due; his table includes both marine and inland terraces. Pissis has observed the necessity of distinguishing between these two formations; he assigns a height of only forty to fifty meters to the marine terraces between the parallels of 31° and 33°. The inland terraces lie at high levels and follow all the windings of the river valleys, while the marine terraces are horizontal, contain sea-shells, and narrow away and disappear as they pass into the transverse valleys [2]. But this last observation of Pissis is not incompatible with the existence of a high-level shoreline, for the lower river terraces are more recent than the upper marine terraces and were partly formed at their expense.

The longitudinal valley of Chili, about 700 meters above the sea in the north, sinks lower and lower towards the south, but no great river arises within it to follow the foot of the Andes, like the Sacramento or San Joaquin in California. Drainage takes place into the sea through the numerous transverse valleys of the coast cordillera. The peculiarities of the valley system, the traces of an ancient high-lying valley-bottom in the north and its intersection by more recent transverse valleys, as well as its continuation southwards to the Moraleda channel, have already been mentioned (I, p. 517). Marine deposits, either Tertiary or

[1] C. Darwin, Geological Observations, pp. 261–263; Mallard et E. Fuchs, Notes sur quelques points de la géologie du Chili, Ann. des Mines, 1873, 7e sér., III, pp. 77–81, pl. ii, fig. 3.

[2] Domeyko, Solevantamiento de la costa de Chile, An. Univ. Chile, 1860, pp. 573–599; Pissis, Provincia Aconcagua, op. cit., 1858, p. 60.

Quaternary, have never yet been encountered in this great excavation. In the sediments which occupy it, *Mastodon Andium* and plant remains are found. It was once a series of inland lakes separated from one another by ridges of ancient rocks, like the lake which now forms the southern boundary of the bay of Reloncavi.

Around the shores of these ancient lakes, however, and eastwards on the slopes of the Andes, terraces are visible up to a considerable height. Domeyko, in describing his ascent of the volcano Tinguiririca from San Fernando, has given us a vivid picture of these inland terraces which rest against the foot of the Andes; three, and in some places four, level terraces, covered with the richest vegetation, rise one above the other. Pissis has traced them along the valleys and through the whole province of Colchagua. He observed four stages in the valley of the Cachapoal from Rancagua to the Rio Cortaderal; the lowest is formed by the plain of Rancagua at a height of 550 meters; the second begins at the confluence of the Rio de Cola and rises to a height of 974 meters on the Rio Cuncle, where the third stage begins; this extends to the confluence of the Rio de los Cipreses, and on this river it occurs at a height of 1,200 meters. The fourth stage finally occurs in the upper region where the river takes its rise, and is cut through by deep gulches. Thus these stages rise on the Cachapoal to a very considerable height, and the origin of each stage corresponds, according to Pissis, with the confluence of a tributary. This is also said to be the case on the river Tinguiririca and on the Teno. The Cachapoal and the Tinguiririca unite to form the Rio Rapel, which enters the sea near lat. 34° S. in the Tertiary region of Navidad. Only six leagues from the coast, terraces are found in this river basin at heights of 271 and 207 meters, surrounding a little isolated valley [1].

Let us now turn our attention further south.

The eastern part of the Andes is bordered in the south by a long series of lakes, the last of which, the Lago *Llanquihue*, is situated between lat. 40° 58′ and 41° 20′ S. It lies only forty-three meters above the sea, and is separated from the gulf of Reloncavi by a barrier of no great breadth; the gulf is the northern end of that arm of the sea which is bounded on the west by the island of Chiloë and the Chonos archipelago, on the east by the Andes; it has long been regarded as the submerged prolongation of the great valley of Chili.

The observations of Stolp and Fonck, and of Gormaz and Juliet, have made known a number of remarkable facts relating to the Lago Llanquihue and the gulf of Reloncavi, that is to say, the very region in which the exposed part of the great valley ends and the submerged part begins.

[1] Domeyko, Estudio del relievo, &c., An. Univ. Chile, 1875, XLVIII, pp. 51 and 60; Domeyko i Diaz don Wenceslao, Excursion jeolojica, &c., op. cit., 1862, p. 23; Pissis, Provincia de Colchagua, op. cit., 1860, p. 691.

Lake Llanquihue is bounded by the slopes of the volcano Osorno on the east, and of the volcano Calbuco on the south-east; between these volcanos is a depression lying chiefly in the recent ejectamenta of Osorno. The depression stretches from lake Llanquihue around the south foot of Osorno to a second and somewhat smaller lake, the Lago de Todos Santos, which flanks the east side of Osorno. The surface of the Lago de Todos Santos lies about 171 meters above that of lake Llanquihue and consequently at a height of 214 meters above the sea.

There is at present no communication between the lakes. The Lago de Todos Santos discharges itself by the rapidly flowing Rio Petrohue to the south into the upper end of the long fjord of Reloncavi, while the Lago Llanquihue sends its outflow westwards into the Ocean by the Rio Maullin.

The whole west and north side and a large part of the south side of lake Llanquihue are formed of recent alluvial land containing no organic remains and divided into stages. Gormaz distinguishes six terraces at heights of from four to eighty meters above the lake, that is, 47 to 123 meters above the sea. Of these, the fourth terrace, at a height of 43·3 meters above the lake, is the most sharply defined and the most constant. Juliet, who accompanied Gormaz, has shown that lakes Llanquihue and Todos Santos and the broad marshy region of Nadi lying west of Llanquihue probably once formed a single sheet of water. Juliet ascribes the existing difference in the height of the two lakes to the simple fact that the Rio Petrohue possesses a hard bed formed of volcanic rocks, and cannot cut its way down it so rapidly as the Maullin, which flows over less resistent material[1].

Here inland lake terraces reach the immediate neighbourhood of the sea.

From the eastern latitudes no Quaternary or more recent shell-beds have yet been made known; the beds mentioned as occurring in Chiloë and the southern islands are either of Tertiary age or they are kitchen middens, or at least suspected to be such. On the other hand, terraces are everywhere well developed; whether there may be some among them in the formation of which ice has played a part is not known, but there is in many respects an evident resemblance between the features of this region and those of northern Norway.

Even in the neighbourhood of *Puerto Montt* steps occur close to the sea, sometimes cut in disintegrated granite, sometimes in volcanic accumulations,

[1] J. Domeyko, Nuevas investigaciones acerca de las gradas en que está cortado el terreno terciario de la costa de Chile, An. Univ. Chile, 1862, pp. 183–186, and map; Vidal Gormaz, Llanquihué, Mem. de Marina, 1872, p. 280, and An. Univ. Chile, 1872, pp. 301, 305, 314, 318, in particular p. 321; C. Juliet, Mem. de Marina, 1872, p. 343, and An. Univ. Chile, 1872, p. 383. In illustration of the preceding I refer the reader to the map of the bay of Reloncavi by Guill. Cox in the Journ. R. Geogr. Soc., 1864, XXXIV, p. 205, and to that of C. Martin, Peterm. Mitth., 1880, XXVI, pl. viii.

or again in Tertiary lignite-bearing beds. East of Puerto Montt, towards *Rio de Coihuin*, the height of the stages has been measured by Gormaz and Martin; there are three stages up to a height of 109·9 meters, then the ground ascends gently up to 126·7 meters; the uppermost stage, here forming the highest part of the country, lies at a height of 149·7 meters [1]. Fonck mentions that stages are not only visible on the island of *Tenglo*, but also on both sides of the channel of Chacao, which is a transverse valley [2]. At the head of the bay of *Castro*, on the east side of Chiloë (lat. 42° 25′ S.), three distinct stages rise on both sides of the little river of Gamboa up to a height of about 500 feet [3].

That part of the coast lying further south now exhibits a very remarkable phenomenon. Not only is the line of the great valley continued through the bays of Reloncavi, Chacao, Corcovado, and still further through the Moraleda channel to the straits of Magellan, but it seems as though there were traces of an ancient system of transverse valleys. The fjords of the east, cutting deeply into the chain of the Andes, correspond to the channels in the west. The channel of Chacao corresponds to the converging incisions of the Boca de Reloncavi and the Boca de Bohodahue. 'The valley of Huemules,' says Simpson, 'corresponds to the Puluche channel, the Aysen to the Agiiea, the Queulat to the Ninualaca, and the Palena and Jictoc to the Huafo, as though in other times they had been straits of the sea like those of Magellan [4].'

Contemplating the map of the Norwegian fjords we are almost tempted to imagine that an approximation to the same arrangement may be perceived there; the manner in which the ancient glacier valley of the Divi, for example, is continued to the Bals fjord, while the existing valley of erosion turns to the west, is so strikingly similar as to arouse a suspicion that some deeper connexion underlies the resemblance.

In lat. 46° 40′ S. lies the *Laguna de San Rafael*. The great peninsula of

[1] Gormaz, Llanquihué, p. 198; Mem. de Marina, 1872, p. 198, and An. Univ. Chile, 1871, p. 70.

[2] F. Fonck, Naturwissenschaftliche Notizen über das südliche Chile, Peterm. Mitth., 1866, p. 467. I have passed over in silence the alleged subsidences within this region, cited by many authors, since in the majority of cases it is only a question of landslips; in the best known example, that of the Laguna di San Ramon, in which a new lake is said to have been formed, a spring seems to have appeared; the case has been discussed by Gormaz, An. Univ. Chile, 1872, p. 230, and Mem. de la Marina, 1872, p. 195.

[3] C. Darwin, Geological Observations, p. 235.

[4] E. M. Simpson, Esploracion hidrográfica de la Chacabuco; Mem. de la Marina, 1872, p. 379, and An. Univ. Chile, 1872, p. 427. Simpson, in describing his exploration of the remarkable lagoon of San Rafael, which illustrates the cutting off of a branch of the sea by a glacier, mentions the traces of recent subsidence in the uppermost parts of the channel of Moraleda. The evidence is found in the submergence of a forest, but in this labyrinth of streams secondary alterations of the water level may be explained in various ways; Simpson, op. cit., p. 178.

Taytao is only connected with the mainland by an isthmus of recent origin, formed by sediments brought down by the glaciers into the sea. Within this isthmus is a lagoon, or rather a lake, of nearly circular outline and eight to nine nautical miles in diameter; towards the north it opens into the sea by a narrow channel, and on the east receives the glacier of San Rafael, which advances as a long tongue of ice four and a half miles into the water. The Jesuit Garcia visited the lake in 1766, and more recently Captain Simpson has twice crossed it. The glacier is constantly 'calving,' and the fragments of ice fall down with a crash like thunder, awakening echoes among the mountains. Its activity appears to be greater by night than by day. The waves, says Simpson, retreat as before an earthquake, and then break in surf along the shore. All around the lake the waves are actively at work, and the destruction of its banks would be far greater if these were not to some extent protected by vegetation. At a distance of one nautical mile from the glacier the bottom of the lake was not reached at a depth of 108 meters [1].

Within the narrow straits, terraces are seen at many places; Coppinger mentions those in the *Fitzroy channel*. In one bay, seven nautical miles west of the bay of Mines, there are two terraces so regular that they might be taken for artificial constructions [2].

Thus the traces left by the sea do not give us so clear and connected a picture on the west coast of South America as on the east. Almost on the equator even, in Guayaquil, a shell-bed occurs containing *Mastodon Andium*. The observations made at Mejillones and on the Cerro Gordo have revealed to us a strand at the height of 441 meters, with indications of an even higher level, yet the few shells known from the beds at these altitudes still indicate a connexion with the Atlantic fauna. The period at which the faunas were separated and the existing fauna made its appearance in the west is not known. In the remaining beds, described as Quaternary, there are no European species, it is true, but the number of extinct species is extremely great. Well-developed terraces may be seen at different heights on the whole of the middle and southern part of the coast; in the fjords and channels of the south no Quaternary mollusca are known, but the geographical features present a remarkable resemblance to those of the northern coasts of Norway.

[1] Simpson, Esploraciones hechas por la corbeta Chacabuco; Ann. hidrogr. Chile, Santjago, 1875, I, pp. 32, 131, et seq.; cf. map in Peterm. Mitth., 1878, pl. xxiv.

[2] R. W. Coppinger, Visit to Skiring Water, Straits of Magellan; Proc. R. Geogr. Soc., 1880, New Ser., II, pp. 552–556.

CHAPTER XIV

THE OCEANS

The boundaries of the Oceans. Eustatic negative movement. Transgressions. Eustatic positive movement. Inadequacy of eustatic movements. River mouths and river terraces. General survey of comparatively recent strand-lines. Oscillations of the Oceans. Alternating equatorial phases. The continents a result of subsidence. No appreciable change of level in the historic period.

The Pacific Ocean is bordered by long mountain chains, and surrounded by volcanos as by a girdle of fire; but no such boundary marks the margins either of the Indian Ocean or the Atlantic. On closer examination the mountains bounding the Pacific are found to be folded ranges, not wholly alike on the east and on the west, but in every case turning their folds towards the abysses of the sea. In California and in South America throughout its length we find, in front of the great ranges, the cordillera of the coast distinguished by its singular stratigraphical succession. The east coast of Asia, on the other hand, is formed of a series of island festoons, which, as a result of a peculiar arrangement, proceed from the crowded chains of central Asia and turn towards the north as they reach the borders of the Ocean.

South America, as far as the isthmus of Tehuantepec, is a self-contained unit; North America is a second; the independent arc of Alaska with the Aleutian islands is a third; eastern Asia, as far south as a line immediately north of Timor, a fourth; and, finally, Australia with New Zealand and a great number of other islands forms a fifth. The Antarctic region is as yet practically unknown.

The Asiatic arcs strike into the mainland; the most southerly of them extends through Java and Sumatra, the Nicobar islands and the Andamans to the coast of Arakan. This is the Burmese arc, the first of the series which bounds Eurasia on the south. These bordering arcs reappear on the north coast of the Persian gulf, and in certain parts of the Mediterranean, to terminate in the sharp bend of Gibraltar. Many of the arcs are accompanied by linear volcanic series. It is only at Gibraltar and in the cordillera of the Antilles that the outer border of a folded range reaches the Atlantic Ocean. With these exceptions the whole outline of the Atlantic, as well as of the Indian Ocean, is independent of the strike of the folded ranges, in other words it is a 'backland'; in the Pacific, on the contrary,

the coasts are already determined by the folded ranges, and the Ocean itself covers the foreland. Cape Horn and the mouths of the Ganges mark, in the two great continents, the sharply defined limit between these two contrasted tectonic systems.

The extremely complex structure of Europe may be resolved into three principal folded chains, lying one behind the other, and all overfolded towards the north. The northernmost range, the Caledonian, is of pre-Devonian age. The second is composed of a western or Armorican segment, and an eastern or Variscan segment; they meet in syntaxis in France, and the junction may be recognized even on the outer border, in the re-entrant angle which is formed near the Franco-Belgian frontier by the Coal measures overthrust to the north. This second chain is of pre-Permian age, but with posthumous foldings, the formation of which was continued at least as late as the Tertiary aera. The third chain, which is the most recent, includes the Pyrenees, the fragmentary arcs in the south-east of France, the Jura, the Alps, and the Carpathians. Each of these chains was dammed back in its course by the sunken ruins of the preceding chain. In the north of Spain we recognize in the basin of Asturias an arrangement similar to that presented by the sharp bend at Gibraltar, but here worn down to the roots by prolonged erosion.

The course of the west coast of Europe is not determined by the trend of the folded ranges, but cuts across it transversely, so that the Armorican arc terminates in a rias-coast on the south-west of Ireland and in Brittany; neither in Galicia nor in Portugal does the orographic structure find any expression in the course of the coast.

At the same time the folded chains of North America turn gradually but completely round in an arc, so that on the lower St. Lawrence, which marks the outer border, the direction of the folding force passes from west through north-west to north-north-west, and the rias-coasts of Nova Scotia, New Brunswick, and Newfoundland thus present a close resemblance to certain parts of the west coast of Europe [1].

This contrast between the outlines of the Ocean basins and the structure of the continents shows in the clearest manner that *these Ocean basins are areas of subsidence*, reproducing, but on a far larger scale, the subsidences with which we have become familiar in the interior of the continents. This is further attested in the case of the Pacific region by the presence of abyssal depths close against the border of the mountain arcs, e. g. on the coast of Japan and the west coast of South America.

This conception is in closest harmony with the observations already made in the Mediterranean. This basin has been shown to consist of

[1] This resemblance is so great that Marcel Bertrand has not hesitated to draw connecting lines across the Ocean; La Chaîne des Alpes et la formation du Continent Européen, Bull. Soc. géol. de Fr., 1887, 3e sér., XV, p. 442, fig. 5.

several sunken areas of different age, and it is manifest *that the outlines of the great Oceans are also of different age.*

That such is the case is shown by the fact that it is not always the same subdivisions of the Mesozoic succession which are visible on the borders of the Oceans. Around the Pacific, marine deposits of the Trias are encountered, as in New Zealand, New Caledonia, Japan, the Aleutian islands, the Queen Charlotte islands, the west of North America and Peru. They are everywhere folded into the great ranges of the coast, and they appear to occur also in Arakan, where the Burmese arc forms the boundary of the sea. They are also present in the extreme north of Eurasia, and in Spitzbergen they retain their original horizontality.

On the shores of the Indian Ocean, except in the north-east, where the coast is constructed on the Pacific type, we do not encounter deposits of this age. Here the series begins at the earliest with the middle Jurassic, and the Mesozoic beds lie everywhere horizontal; subsequent folding is nowhere visible. The plant-bearing Gondwána beds, which were certainly not formed in the sea, face the Ocean in a denuded fault-scarp, as in the Quathlamba mountains. On the summit of the vast South African table-land traces of the presence of the sea have nowhere been observed, nor is it possible to conceive in what way this lofty mass could have been raised out of the Ocean.

Around the Atlantic Ocean—again excepting the fragmentary arcs of Gibraltar and the Antilles, constructed on the Pacific type—the series does not begin before the middle Cretaceous; this is the case from cape Horn to Greenland, and from the Lofoten islands to the cape of Good Hope; in west Africa the series may possibly begin with a slightly older stage. In the west of Europe, it is true, Lias and Jurassic reach the sea, but the existing shore by no means corresponds to that of those periods; this is evident from the fact that the mighty fresh-water deposits of the Weald in the Charente, in Santander, and on the coast of Portugal, strike freely out to sea, like the Gondwána beds of the Indian peninsula, and the late fresh-water Tertiary beds on the shores of the Aegean.

As soon as we recognize the Ocean basins as sunken areas, the continents assume the character of horsts, *and the wedge-like outlines of Africa, India, and Greenland, all pointing towards the south, find their explanation in the conjunction of fields of subsidence which reach their greatest development in the same direction.* In Greenland the difference in the stratified succession shows that the two sides of the wedge are probably of different age; that on the east being apparently older than that on the west. The wedge-shaped outline of South America is of different origin; in this the curved folded range of the Cordillera plays the essential part.

The crust of the earth gives way and falls in; the sea follows it. But while the subsidences of the crust are local events, the subsidence of the

sea extends over the whole submerged surface of the planet. It brings about a general negative movement.

As a first step towards an exact study of phenomena of this kind, we must commence by separating from the various other changes which affect the level of the strand, those which take place at an approximately equal height, whether in a positive or negative direction, over the whole globe; this group we will distinguish as *eustatic movements.*

The formation of the sea basins produces spasmodic eustatic negative movements.

Such movements have occurred at various periods and in different degrees. The structure of Spitzbergen and Scotland shows what important subsidences took place within the Palaeozoic aera; the structure of Scania illustrates the continuation of these movements through different stages of the Mesozoic aera; the recent history of Iceland shows that there a similar formation of horsts and troughs is still in progress at the present day. This fragmentation of the globe by great fractures of different age is, however, a phenomenon of wide distribution. The marine deposits of the Trias, and with them the complete series of the marine Mesozoic, traverse the greatest existing continent in a zone which coincides to no small extent with that of the arcs forming the southern boundary of Eurasia; and thus it happens that great mountain ranges now rise over the site of the ancient sea, and there, where further to the west lay its greatest depths, we now encounter the eastern Alps; this sea was continued across the western Mediterranean and some parts of western Europe. The correspondence of the faunas in the contemporaneous deposits of the West Indies, Bogota, and Chili, persisting in Chili and the Antilles even into the Tertiary period, compels us to suppose that an ancient communication, older than the northern as well as the southern part of the present Atlantic, existed across this Ocean, precisely in that region which, by exception, is constructed on the Pacific type, namely the Antilles with their folded cordillera and girdle of volcanos. This is the ancient sea, extending parallel to the equator, which Neumayr has designated the *Central Mediterranean.*

If we now consider the succession of stratified systems in those parts of the continents which have so far been closely investigated, we discover that vast areas have been subject, during periods of extraordinary duration, to marine transgressions, that is, positive movements which have been interrupted by negative phases. At the close of the Silurian epoch, the strand receded across the whole region lying between Illinois and the Atlantic Ocean, as well as in England, the north of Russia, and the neighbourhood of the Dniestr. The Old Red sandstone, containing no marine fossils, and shales of the same age likewise of non-marine origin, were deposited over the whole of the North Atlantic region, in the east of Canada, Spitzbergen, Scotland, England, and the north of Russia as far as the Dniestr. Then the sea began its

advance, and in the middle Devonian the transgression was established over Russia as far as Livonia and Courland, probably also in western Canada, on the Clear Water and the Mackenzie, and perhaps as far as the Arctic Ocean. A fresh negative phase marked the beginning of the Carboniferous period, succeeded by another positive phase, which brought about the transgression of the Carboniferous limestone in California, Dakota, and Texas in the west, and in the east over the Old Red sandstone region, which stretches from Ireland across Scotland to Spitzbergen, and many other places, as well as over much older deposits in the north of China. Then followed the oscillations of the upper Carboniferous period, which were felt alike in Illinois and in many parts of southern Europe, until the negative movement was again interrupted, and the marine sediments of the Permian epoch were deposited over a restricted area in North America and northern Europe.

The Mesozoic seas of Europe were subjected from the Rhaetic period onwards to a positive movement, which, though interrupted by occasional secondary phases of retreat, never failed to regain its ascendancy; this movement gave to the sediments of the seas a continually increasing extension, until finally the deposits of the middle Jurassic, encroaching on a foundation of very various age, extended through Cracow, Kiev, Moscow, and Orenburg, and northwards up the Petchora almost as far as the Arctic Ocean; covering at the same time the north of Scotland in the west. A very large part of Europe was thus submerged; and indications of this great transgression are also found in Abyssinia, in Cutch, and even on the west coast of Australia.

The submergence continued, and the Kimmeridge stage of the upper Jurassic, maintaining almost constant characters throughout its course, may be traced from Orenburg and Simbirsk across central Europe into the neighbourhood of Lisbon. Then the strand receded, and the sea was left in possession of those regions only from which the transgressions had proceeded, principally the Alps, while from Hanover to the south of England, on the Charente, in north Spain and Portugal, great fresh-water lakes came into existence.

At this stage the Cretaceous epoch began. From the Alps, and the Balearic isles which form their continuation, the strand gradually advanced again across the region of the existing Jura into Spain. By degrees the whole of central Europe, together with all the sediments of its great fresh-water lakes, was again covered by the sea. At the time when the previous period of retreat had reached its maximum, Russia was converted into dry land, but with this fresh advance from the south the sea simultaneously extended from the north and crossed the Russian plain, bringing with it a number of independent types of mollusca; it first reached Tomaszov on the Pilica in western Poland, and subsequently, during the deposition of the upper parts of the lower Cretaceous, the two seas conjoined, and some

Russian types made their way as far as Hanover. The northern influence then disappeared, while the southern sea steadily continued to gain in extent. We thus reach the climax of the great middle and upper Cretaceous transgression.

Then for the first time the Atlantic coasts were washed by the Ocean. The sea covered the plains of Patagonia as far as the east border of the cordillera, it advanced to the upper tributaries of the Marañon, perhaps across the whole continent of South America; from Texas it made its way through the middle of North America as far as lat. 65° N. It left its traces around the greater part of Africa, covered a very large part of Europe, passing over the ancient horsts, and extending through the south of Russia east of the Urals to lat. 62° 30′ N.; thence it proceeded over the Caspian, the sea of Aral, Turania, Persia, Syria, Arabia, the eastern Sahara, the coasts of India, and other vast areas. If we seek a region which was unaffected by this transgression we shall discover it in the north; the east of Greenland, Spitzbergen, north Russia and north Siberia (with the exception of the region just mentioned in the eastern Urals), and the north of China have so far afforded us no trace of the Cretaceous sea.

Once more vast areas were abandoned by the sea. Everywhere the strand receded; in Europe even to a greater extent than after the Jurassic transgression, for the fresh-water lakes which now came into existence lay further south and close to or upon the area of the ancient central Mediterranean, from which the various transgressions had proceeded; as, for example, in the south of France, and more particularly in Istria and Dalmatia.

The Cretaceous epoch comes to an end and the Tertiary aera begins. Now, however, the conditions become so complicated that it is no longer possible to give a general and concise account of them. The Oligocene transgression from the north, the gradual retreat of the sea from the heights of Persia and central Europe which took place within the limits of the existing Mediterranean, and the partial extension of this sea by local subsidences are some of the most striking features of this eventful period.

This recapitulation shows that *the theory of secular oscillations of the continents is not competent to explain the repeated inundation and emergence of the land.* The changes are much too extensive and too uniform to have been caused by movements of the earth's crust. The middle Cretaceous transgression presents itself on the Amazon, the Athabasca, the Elbe, the Nile, the Tarym, and the Narbada, in Borneo and Saghalien, and on the Sacramento; it marks a general physical change which affected the whole surface of the planet. In this lies the explanation of the remarkable fact that it has been found possible to *employ the same terminology to distinguish the sedimentary formations in all parts of the world.* This would have been impossible if the limits of the formations had not been drawn by natural processes simultaneously in operation over the widest areas.

It has been fortunate for stratigraphical geology that its earliest development took place in England, a region where the frequency of gaps in the stratified series neither rises above nor falls below the mean, a region which has at times been submerged beneath the sea, at others covered by fresh-water lakes or left exposed as dry land. A whole series of marine faunas, which are indigenous in more southerly regions, such as the Hercynian, the upper Carboniferous, that of Artinsk and those of the various zones of the Trias, the Tithonian and the Neocomian, are either entirely absent from the stratified series in England or only imperfectly represented. *The limits of the formations established by William Smith and his successors correspond for the most part with negative phases.* Where they have been most precisely studied, as in the case of the limit between the Jurassic and Cretaceous, our knowledge has been extended into details, and we now perceive that by a movement in the negative direction arms of the sea become isolated and the fauna impoverished, although its final extinction may be delayed till the negative movement has passed its maximum.

In this also we find an explanation of the difficulties which were encountered in correlating the stratified series where it attains its complete marine development, as in the eastern Alps, with the succession established in England. In this again we recognize the source of the opinion expressed by many eminent investigators to the effect that this succession stands in relation to certain cycles, i. e. a perpetually recurring alternation produces a periodic return of similar conditions.

As to the precise nature of these phenomena we can only hazard conjectures; the present state of observation does not justify any definite opinion. Some features may be clearly distinguished, others are still doubtful. The analysis of the Rhaetic series in the Alps shows that the positive movement, which carried the Rhaetic shore further and further outwards till it finally extended across a large part of central Europe into the north of Scotland, must have been *oscillatory*. The division of the limestone into beds, the terrestrial or littoral remains in the earliest 'partings,' the fragments of red earth in the white limestone, and other indications point in a concordant manner to this conclusion. Another example of the same kind is furnished by the alternating series in the island of Purbeck. The recent limestone beds of Sombrero and the remains of guano between them point in the same direction. On the other hand it cannot be denied that the paralic seams, intercalated with the marine Carboniferous beds, are extremely similar to the partings of the Rhaetic in the eastern Alps, and that the union of such seams as they are traced landwards to form a single thick bed cannot be explained by oscillatory movements in the light of our present knowledge; but this question requires a fresh and detailed examination. Still, there can be no doubt that the evidence afforded by the Rhaetic series and by the Purbeck is strongly in favour of numerous subsidiary

oscillations. Oscillations of greater importance may be recognized with certainty, such, for instance, as those which caused the stages of the Lias to extend in transgression, some to a greater, others to a less distance; this may be seen from a comparison of the succession in the north of Scotland with that of Scania and perhaps also with that recorded by the Hierlatz beds of the Alps. These represent in other words secondary cycles within the primary. The principal phases or the primary cycles reveal themselves with even greater definiteness.

But it is a striking fact that in the best known of these primary cycles the positive phase is of much greater duration than the negative phase which follows it. In the present state of the question it is hardly possible to say anything definite or conclusive on this point; yet we must not forget that from the Trias through the Rhaetic, the Lias, and the Oolites to the Oxfordian —that is, through an extremely long period of time—the strand gradually advanced across Europe, with a few interruptions of slight importance; even as late as the Kimmeridge the sea extended from Siberia across Europe to the existing Atlantic coast, and then, in a period, as we may conjecture, of incomparably briefer duration, corresponding to the Portland and Purbeck, a general emergence took place, giving rise first to the lagoons in which gypsum was deposited, and then to the great lakes of the newly exposed land. The same process is repeated during the Cretaceous epoch. In Europe a study of the existing observations leaves the impression that during the first half of this period the inundation proceeded from both north and south, till the advancing faunas met and intermingled. Later on, during the Cenomanian, it was only the southern region which extended further and further towards the north, but the movement continued into the Senonian, when the sea attained an extraordinarily wide extension. At that time there was much less land on the globe in the temperate and tropical latitudes than at present, although over large areas the sea was perhaps of no great depth. It is difficult to say whether the brackish-water character of the Laramie stage is to be ascribed rather to the deposition of alluvial sediments or to a retreat of the strand; in Europe we witness after the Senonian a general withdrawal of the sea, proceeding to all appearance with incomparably greater swiftness than its previous advance, and to so great an extent that it gave rise to fresh-water lakes in the south of France and in the northern Adriatic.

The extraordinarily slow rate at which some positive movements have taken place is also indicated by the plain of erosion which may often be seen at the base of an unconformable junction. It is probable that the detailed study of certain beds of phosphates possessing a wide distribution might lead to the same conclusion.

The retreat of the sea at the close of the Jurassic period laid bare the region on which the new flora of dicotyledonous trees supplanted the older vegetation. The Cenomanian transgression, as it advanced over North

America and Europe, buried up the remains of this new flora in its earliest deposits. In like manner the post-Cretaceous emergence gave birth to the land over which, in North America as in Europe, the higher mammals distributed themselves.

There is no difficulty in perceiving how slowly the transgressions advanced over the land; the Cretaceous transgression, for example, begins in Texas with sand containing Dinosaurs; the Caprotina limestone of Friedrichsburg and the Washita series which follow hardly extend beyond the boundaries of this State; even the Dakota beds which come next only furnish marine species as far as New Mexico and Kansas, and in the latter State these species are littoral; in Dakota they are such as flourish in water of less than the normal salinity; and it is not until later that the influence of the sea makes itself felt as far as Canada[1].

Finally, the regular and uniform character of the movements may be recognized from the concordant superposition of the more recent beds on those of much greater age. Of this there are numerous examples. Murchison, in describing the recent marine beds with Arctic shells at Ust-Waga on the Dwina, has pointed out their absolutely conformable superposition on the horizontal Permian sediments; he has also shown how at other places the latter sediments rest in perfect concordance on much older beds, so that the stratigraphical relations offer no hint of the great gap which occurs at the line of contact. That this should be the case may well be cause for astonishment, for some degree of erosion, weathering, or other alteration of the surface must have occurred in the interval, and I can scarcely help thinking that even in this case some kind of erosion, though feeble perhaps in its effect, must at one time have been active.

The question now presents itself as to whether these positive movements were likewise eustatic.

Material is continually being carried into the sea; some, in mechanical suspension, sinks to the bottom near the coast as clastic sediment; some, in chemical solution, is transformed by living organisms into calcareous or siliceous shells. There are besides volcanic products which accumulate in the depths of the sea. The thickness of the ancient sediments and the extensive denudation of the continents, amounting in many places to thousands of feet, show how great is the bulk of material which has been carried into the sea in the past. The oceanic regions are filled up slowly but without intermission, and their waters in consequence are gradually displaced; at the same time the transgression which thus results is facilitated by the progressive denudation of the land.

The formation of sediments causes a continuous, eustatic positive movement of the strand-line.

[1] C. A. White, On the Cretaceous Formations of Texas and their relation to those of other portions of North America; Proc. Acad. Nat. Sci. Philadelphia, 1887, pp. 39–47.

We are thus acquainted with two kinds of eustatic movement; one, produced by subsidence of the earth's crust, is spasmodic and negative; the other, caused by the growth of marine deposits, is continuous and positive (σ, II, pp. 220, 267). This distinction may be best illustrated by a few simple calculations, even though the results should be, as indeed they must, only very roughly approximate. As early as 1848, the acute observer, Chambers, attempted to estimate the extent to which the surface of the sea would be lowered by a local subsidence of the sea floor [1]. Let us take a region which is known to have sunk down in comparatively recent times, as, for example, the Graeco-Levantine sea together with the Pontus; first let us suppose that this area was not previously occupied by an inland lake, and further, that the Oceans descend perpendicularly from their shores; then, basing our calculation on Krümmel's estimate of the volume and mean depth of the Ocean, we shall find that the formation of the subsidence under consideration would produce a eustatic negative movement to the extent of nearly four meters over the whole surface of the planet. On the other hand, it would require the denudation of all the continents to the extent of ten meters to produce a eustatic positive movement of the same amount. According to Krümmel the mean depth of the Ocean is 3,438 meters, and the area of the surface 366 or 368 million square kilometers; hence the subsidence of a continental surface of something more than 100,000 square kilometers to a depth equal to the mean depth of the Ocean would be required to produce a general sinking of the sea-level to the extent of one meter.

If there were any reason to suppose that the quantity of water existing on the surface of the planet is not constant, but subject to increase or decrease, as a result of general causes, whether telluric or cosmic, then the resulting phenomena would fall within the category of eustatic movements. It is probable indeed that a diminution does actually occur in the formation of new mineral silicates, and an increase also, as a result of volcanic eruptions.

The observations at our disposal, as to the extension of the ancient seas, are, it is true, extremely incomplete; and, so far as they go, they do not seem to indicate that the eustatic movements are sufficient to explain this extension. The existence of eustatic movements admits of no doubt; their action is shown by the rapidity of the great negative movements, particularly at the close of the Cretaceous period; in other words, we have good reason to suppose that the limit between the Cretaceous and Tertiary which corresponds with the appearance of the dry land on which the higher mammals were evolved, was produced by an Oceanic subsidence. Proofs are wanting for any particular case. On the other hand, there are other phenomena which do not present the characters of eustatic movements.

A close examination of the stratified series often leads us to suspect the

[1] Chambers, Ancient Sea Margins, p. 319.

existence of numerous smaller oscillations which are hard to reconcile with eustatic processes.

We have no evidence as to the existence of Mesozoic sediments in high southern latitudes, since these are covered by sea and ice; in the Arctic regions, the great Mesozoic girdle which runs from Prince Patrick's island across the north-western part of Bathurst towards the islands north of Grinnell island is almost entirely unexplored. Still, notwithstanding these deficiencies, we have been able to obtain the following results :—

(1) The transgression which continued through the Rhaetic, the Lias, and Jurassic, started in Europe from the central Mediterranean, i. e. from the region of the Alps, and proceeded towards the north; at the same time it left its traces far towards the south in Abyssinia and Cutch; (2) in the lower Cretaceous period (Volga stage) a transgression made its way over north Russia and Siberia, and indications of a similar transgression also occur in the southernmost part of Africa (Uitenhage series), and in Australia (Aptian stage), as well as far to the south in Cutch and central Europe; (3) the Cenomanian transgression proceeded from the warmer zones towards the north and south, and, although very widely extended, it left unsubmerged a large region in the north (east Greenland, Spitzbergen, north Russia, parts of Siberia, and north China); (4) the Eocene transgression nowhere extended into the Arctic regions; (5) the Oligocene transgression, on the other hand, probably came from the Arctic Ocean, and proceeding along the eastern side of the Urals entered Germany. A certain contrast or compensation appears to exist between the equatorial and the polar regions; but all statements in this connexion must be regarded as provisional, liable at any time to be confirmed or modified by the progress of discovery.

Let us now turn our attention from the ancient seas to the more recent sediments which rest against the slopes of the existing coasts, and the various traces left by the displacement of the strand. In addition to local sources of error, which have already been illustrated by examples, there are many others of a more general nature. The first and most important, as I may venture once more to point out, is to be found in the great difficulties which attend a chronological correlation of facts observed at widely separated localities. In high latitudes the traces left by the ice afford evidence which must be employed with great caution, for there has been more than one glacial episode; there is no proof whatever that the ice disappeared at the same time in the north of Norway and in central Europe, while in Greenland it still persists. In the tropics we have not even this criterion. It becomes more and more evident that since the period of maximum glaciation and the beginning of historical tradition (the latter also different in different parts of the world) considerable displacement must have occurred. But there is no possibility of deciding whether the negative traces in the vicinity of cape Comorin or at Mejillones, for example, are older or younger than

those of the extreme north, and we are reduced to conjectures. We only know that the period during which these deposits were formed must have been of great duration; on the coast of Guayaquil, *Mastodon Andium* occurs in a recent shell-bed, and at Calais, as well as on the lower Lena, *Elephas primigenius* is of later date than the recent shell-beds which contain remains of the existing fauna of the adjacent seas.

It must also be borne in mind that the employment of numerical data lends to the whole of this branch of inquiry an appearance of exactitude which it does not really possess. The boreholes of Pholas or an abandoned strand-line may mark a water level with some approach to exactitude, but as a rule our only evidence is afforded by shell-beds or other deposits, and the height of these was obviously not that of the sea at the time.

Finally, every attempt which has been made to correlate the displacements observed in various latitudes is seriously affected by the disproportion, as regards the chances of observation and examination, which exists in favour of the traces left by negative as opposed to those left by positive movements. It has been shown that even in the case of oscillations with a considerable positive excess, the chances are that only a single negative trace will be observed (II, p. 25). As a rule the positive movement is masked, and proof of the movement can only be obtained in the tropical regions, where, according to Darwin's theory, which in the main I am inclined to accept, it is furnished by the upward growth of coral reefs. In colder seas, where coral reefs are absent, there is no possibility of such proof, and, in the north as in the south, if a positive movement were in progress, proceeding at no greater rate than in the case of coral reefs, it would leave no sign of its existence.

Attempts have sometimes been made to show that positive movement may be inferred from the form of the submarine slopes off the coast. The most important argument rests on the fact that at the mouths of a number of rivers a furrow has been observed, which, as it were, continues the channel of the river down to considerable depths below the sea.

The river *Hudson*, near New York, affords an example which has been studied in some detail. Lindenkohl shows that the submarine channel first becomes clearly expressed at a distance of about ten knots from the coast; in this case there is a clayey flat at −17 fathoms; the channel lies at −25 fathoms, and is therefore 8 fathoms deep. The depth, however, increases; at a distance of 20 knots the flat bottom lies at −27 fathoms, the channel at −42 fathoms. At a distance of 40 knots the flat lies at −43 fathoms; the channel is now less marked, and subsequently dies out. Soon, however, it reappears in the form of a broad valley. At this distance from the shore a very continuous and fairly steep submarine cliff follows the coast and is crossed by the valley which is very deeply excavated in it. At a distance of 85 knots the channel again appears, and at 105 knots it has reached the

foot of the cliff. In this part of its course, from knot 85 to 105 it lies first at a depth of −60 fathoms, sinks within the first knot to −200 fathoms, and ends in −474 fathoms. It is here 3 knots broad. The lower half of this deep valley, which has been termed a 'submarine fjord,' is bounded by slopes 2,000 feet in height and inclined at an angle of more than 14°; both slopes and bottom are covered with a green sandy mud.

The existence of this submarine channel as a prolongation of the river valley, and of a similar conformation on the coast of California, south of cape Mendocino, has led to the conclusion that the surrounding land must have experienced very considerable subsidence[1]. As opposed to this view we may first cite the observations of Hörnlimann, who has discovered similar furrows in lake Constance at the mouth of the *Rhine*, and in the lake of Geneva at the mouth of the *Rhone*. The ravine of the Rhine has been traced to a distance of 4 kilometers and to a depth of −125 meters; it is excavated in the sub-lacustrine deltaic cone, and where most strongly developed it reaches a breadth of 600 meters and a depth of 70 meters. That of the Rhone has been mapped for a distance of 6 kilometers; 800 meters from the shore the height of its slopes is 50 meters. According to Forel the rate at which sediment is being deposited over this region is so great that every trace of the ancient form of the lake bottom must by this time have been buried up. We must thus be dealing with a recent feature, produced on the surface of the deltaic cone by forces which are still active. According to Forel the 'ravine' is the result of erosive processes, and it points to the existence of a current at the bottom of the lake. Forel attributes the current to the lower temperature and the turbidity of the river water as it enters the lake; the action is probably strongest in spring[2].

The grandest example of this kind, however, is that at the mouth of the *Congo* described by Buchanan. Here there is a deep submarine cañon with steep walls of mud; 20 knots above the mouth the river already exhibits the extraordinary depth of −150 fathoms, and the submarine furrow has been traced to a distance of nearly 100 knots outside the mouth at depths of −1,000 fathoms; 35 knots from the coast the cañon is sunk 3,000 feet deep in the submarine plain. Buchanan believes that there is an undercurrent of sea water which forces its way into the river channel and prevents the deposition of sediment along its course; thus the cañon owes its existence not to excavation, but to the accumulation of sediment on either side[3].

[1] A. Lindenkohl, Geology of the Sea-bottom in the approaches to New York Bay, Am. Journ. of Nat. Sci., 1885, XXIX, pp. 475–480, map; G. Davidson, Submarine Valleys on the Pacific Coast of the United States, Bull. Cal. Acad. Sci., 1887, II, pp. 265–268.

[2] F. A. Forel, Les Ravins sous-lacustres des fleuves glaciaires, Compt. rend., 1885, CI, pp. 725–728.

[3] J. Y. Buchanan, On the Land Slopes separating Continents and Ocean Basins,

In any case these submarine valleys cannot be regarded as indications of a positive movement.

The opportunity of directly observing positive movements thus seldom or never occurs outside the seas containing coral reefs, but indications of negative movement are to be found on all sides. In the higher latitudes they are often accentuated by the masses of débris which were distributed during the last stages of the glacial period or soon after its close. The transport of sand or loose stones was so considerable that in North America some valleys have been completely filled up and levelled over, and the rivers have had to excavate for themselves new beds. Dana, Berendt, and other observers have thought that the cause of these phenomena is to be found in the rapid melting of ice or snow, occurring perhaps repeatedly, and producing overwhelming floods [1].

Not only are marine strand-lines cut in these and other accumulations of like kind, but also terraces which occur far inland and even in the high valleys of the mountains; sometimes also they furnish material for littoral bars and spits. Some of the terraces were formed in lakes, often probably in glacial lakes; others owe their origin to rivers. We have often had occasion to insist on the necessity of distinguishing between fluviatile and marine terraces. The mode of formation of most river terraces is as follows. The water in its efforts towards equilibrium swings in serpentine curves on the surface of the alluvial land. During high water, when the centrifugal force is increased at the bends, the radius of curvature is diminished and the river cuts terraces in its convex banks. As this work proceeds, the river sinks its bed deeper, and the serpentine curves are displaced; the radius becomes gradually less, and from time to time it happens that the convex side of a bend comes into the vicinity of an ancient cliff, at a lower level. It then forms a second terrace; later, perhaps, a third, and so on. Thus the cause of the terracing is the wandering of the meanders combined with deepening of the bed. Hitchcock, as early as 1857, very nearly arrived at this explanation. Rütimeyer, Miller, Mühlberg, and Nikitin successively rediscovered it while studying the rivers of Switzerland, Great Britain, and Russia; it has long been known to the engineers who are occupied with the regulation of mountain streams [2].

especially those on the West Coast of Africa; Scott. Geogr. Mag., 1887, III, p. 222. Buchanan mentions other ravines of the same kind on this coast, and also records one at the mouth of the Adour.

[1] J. D. Dana, On Southern New England during the Melting of the Great Glacier, Am. Journ. Nat. Sci., 1875, 3rd ser., X, pp. 168–183; G. Berendt, Die Sande im norddeutschen Tieflande und die grosse diluviale Abschmelzperiode, Jahrb. k. preuss. geol. Landesanst. f. 1881, Berlin, 1882, pp. 482–495.

[2] E. Hitchcock, Illustrations of Surface Geology, Smithson. Contrib., 4to, Washington, 1857; L. Rütimeyer, Ueber Thal- und Seebildung, 8vo, Basel, 1869, p. 137 et seq.; H. Miller, River-Terracing, Its Methods and their Results, Proc. R. Phys. Soc. Edin., 1883,

Important displacements of the strand must affect the fall of the rivers for a great distance inland, especially in the absence of cataracts. But the river terraces near the sea are of course more recent than the latest movements of the strand. An example is afforded by the Divi, with its recent terraces in the midst of the region of ancient strand-lines and the steps left by the glacial lakes [1]. This is the reason also why terraces are present in all latitudes wherever there is a sufficient supply of loose material; we have already mentioned their occurrence on the Marañon, Gabb describes them in Haiti, but they are chiefly developed in the higher latitudes.

Having thus eliminated, as far as possible, the various sources of error, we arrive at the following conception of the recent oscillations of the strand.

The Arctic coasts exhibit traces of negative movement at a height which is at first considerable, but diminishes towards the south; it depends on the structure of the country, the simplicity of the coasts and their subsequent denudation, whether this diminution appears with a greater or less degree of continuity. The diminution, however, appears to take place at a different rate on different coasts; in North America, for example, the descent is more rapid on the east coast than on the west.

In South Africa, in the south of Australia, New Zealand, and Patagonia, there are also traces of negative movement at a considerable height. In New Zealand and in the east of South America a decrease of this height has been shown to take place towards the north. The east of Australia seems to correspond with a recent fracture. The west of South America also exhibits negative traces in the higher latitudes, but there the case is complicated by the existence of kitchen middens, terraces, supposed to be of inland origin, and other sources of error. The other coasts (South Africa and West Australia) are so little known that the height of the negative indications presented by them must be left out of account.

On the west coast of South America high-level negative traces occur up to lat. 27° S., but it is not yet certain whether beds such as those of Mejillones and Cerro Gordo should not be assigned to an earlier period.

Where negative traces occur up to a considerable height they are interrupted, i. e. they occur at intervals, twice, thrice, or even ten times, one above the other at different levels.

Negative traces occurring at a moderate or trifling height are known also in the tropics, e. g. close to the equator at Guayaquil and on the east coast

VII, pp. 263–306; F. Mühlberg, Die heutigen und früheren Verhältnisse der Aare bei Aargau, Programm Aarg. Kantonsschule, 4to, Aarau, 1885, pp. 1–46, map; S. Nikitin, Die Flussthäler des mittleren Russland, Mem. Acad. Imp. Sci. St.-Pétersb., 1884, 7e sér., XXXII, No. 5, p. 19.

[1] Terraces formed by transportation are described by Dausse, Nouvelle note sur les terrasses alluviales, Bull. Soc. géol. de Fr., 1868, 2e sér., XXV, pp. 752–762.

of Africa. They are clearly exhibited around the whole of the northern region of the Indian Ocean, especially in the Indian peninsula; and they are found up to a height of about 100 meters above the existing sea-level through a very large part of the Polynesian islands, in the midst of the Pacific Ocean and its coral reefs.

Positive indications, such as coral reefs with lagoons, only occur in the warm seas. In the Pacific, however, it is obvious that the living reefs are more recent than the tabular masses of limestone (exposed by negative movement) which they surround; this is also true of the West Indies; and in all these regions the latest movement was evidently positive.

Thus it appears that in the warm seas oscillations have certainly occurred, and hence it would seem to follow that the interrupted negative indications both of the northern and the southern regions are likewise the result of genuine oscillations.

In the West Indies and the sea of Banda, as well as in several other regions, difficulties arise owing to the presence of Tertiary limestones, of which the upper limit can scarcely anywhere be certainly defined [1].

All the relics of ancient shore-lines of which we have made mention are always horizontal and absolutely independent of the structure of the coasts. They present the same characters in the Pacific as in the Atlantic region, on the Archaean foundation as on volcanic superstructures, on stratified table-land, or folded mountains, whether ending in rias coasts or not. In the extremely rare cases in which recent tectonic accidents are found in the same region as these traces—on the shores of Cook strait, for example—the two classes of phenomena exhibit as complete an independence one of the other as the inland terraces of the desiccated lake Bonneville and the recent faults of the Wahsatch.

Although in regard to these questions so much still remains obscure and calls for further investigation, yet it is evident that of the hypotheses propounded to account for such movements, there is one series which cannot be reconciled with the facts, as these are already known to us.

Movements like these, which present themselves as oscillations, and extend around all coasts and under every latitude in complete independence of the structure of the continents, cannot possibly be explained by elevation or subsidence of the land. Even as the transgressions of the ancient periods are much too extensive and uniform to have been produced by movements of the lithosphere, so too are the displacements of the strand-line in the immediate past.

It is also impossible to reconcile these observations with the theories

[1] That the higher horizons are continued from the sea of Banda into the Indian Ocean is shown in particular by an observation made by Aldrich on Christmas island (lat. 11° S.) south of Java; Nature, XXXVII, Dec. 29, 1887, p. 204. The summit at a height of 1,200 feet is composed of coral limestone, and apparently three strand-lines are visible.

which assume an alternating accumulation of water at each of the poles in turn as was suggested by Adhémar. The development and altitude of the negative indications in the higher latitudes, both of the northern and the southern hemisphere, are directly opposed to such an assumption.

As far as we are in a position to judge it appears much more as if that which characterized the more recent movement was an accumulation of water towards the equator, a diminution towards the poles, and as though this last movement were only one of the many oscillations which succeed each other with the same tendency, i. e. with a positive excess at the equator, a negative excess at the poles.

Negative traces are to be seen in all latitudes. We may attempt to explain them by means of eustatic negative processes, i. e. by great subsidences, but this would presuppose a uniform sinking of the sea-level to the extent of more than 1,000 feet in quite recent times. It is much more probable that the negative traces at considerable altitudes in the tropics are not of the same age as those in high latitudes, and that an accumulation of water occurs alternately at the poles and the equator. Among these traces there may be one or more of a eustatic negative origin, but if so, we have not yet learnt how to distinguish them.

This result accords well with the oscillatory nature of the ancient movements to which the alternation of strata so often points. It is equally in harmony with that singular compensation which seems to find expression in the distribution of many formations in Europe. Stratigraphical terminology was created in a region which is, as it were, the field of inundation of the transgressive central Mediterranean. This explains the number of lacunae in the stratified series of England. The negative phases mark as a rule the limit of formations, but which of them were produced by oscillation and which by eustatic movement, we cannot at present determine with certainty.

These conclusions and conjectures are consistent with an opinion expressed by Penck, that the accumulation of ice in high latitudes during the glacial period must have caused an increase of attraction [1]. But it is only as one of many causes which have influenced the sea-level at different times that Penck has called attention to this factor, and it is only as such that it must be regarded; it must not be forgotten that most of the strand-lines which have engaged our attention are more recent than the maximum extension of the ice. In addition to this we have also to take into account

[1] A. Penck, Schwankungen des Meeresspiegels, Jahrb. geogr. Ges. München, 1882, VII, pp. 47–116; A. de Lapparent, Le Niveau de la mer, Bull. Soc. géol. de Fr., 1886, 3e sér., XIV, pp. 368–385; Hergesell, Ueber die Aenderung der Gleichgewichtsflächen der Erde durch die Bildung polarer Eismassen und die dadurch verursachten Schwankungen des Meeresniveaus; Gerland, Beiträge zur Geophysik, 8vo, Stuttgart, 1887, I, pp. 58–114; E. von Drygalski, Die Geoid-deformationen der Eiszeit, Zeitschr. Ges. Erdk., Berlin, 1887, XXII, pp. 169–280.

the different degrees of attraction of the continental masses, the local increase of attraction due to the accumulation of sediment (*a*, II, p. 219), a subject to which Zöppritz has devoted particular attention, and finally a great number of secondary circumstances, such as the direction of the shore with regard to that of the tides, the influx of fresh water, the rate of evaporation, and so forth.

Provided with these provisional results, let us now return to the movements of the outer crust of the earth, and to the various kinds of dislocation which are produced by telluric stresses.

Our observations on dislocations, taken as a whole, cannot be reconciled with any attempt to explain this class of phenomena by means of the elevation theory, i. e. by an undulation of the lithosphere. Neither the numerous small oscillations can be thus interpreted nor the great ones which embrace the whole globe. Movements of the lithosphere do not explain why the stratified series presents the same lacunae in the United States and in central Russia, nor do they explain the formation of long horizontal strand-lines in complete independence of the structure of the land [1].

It is true that the earth's crust has experienced tangential as well as vertical movements; mountain chains have arisen over long zonal areas, and their appearance has been accompanied by profound local disturbances, but it is not on such processes as these that the general level of the Ocean depends. This is shown in the clearest fashion by the Alps; they rear themselves over the site of the central Mediterranean sea, from which time after time transgressions have set forth to pursue their way towards the north and towards the south. As a result of tangential thrusts the sediments of this sea were folded together and driven upwards as a great mountain range, and the Alps have therefore been described as a compressed sea. But this lateral folding has not produced any direct or perceptible effect on the level of the Ocean. The indirect result of folding when it takes place on dry land is to increase the fall of the rivers and to accelerate denudation and the transport of sediments. In the case of folding beneath the sea the causal connexion between subsidence and folding must be taken into account, and this will be discussed later on.

In rare instances a dome of somewhat greater amplitude may be produced by lateral compression, and cases occur such as Diener has observed between Lebanon and Anti-Lebanon; but even this is of no great weight in the balance when set against the other factors which determine the general level of the Ocean [2].

[1] This conclusion, that the elevation theory is inadequate or unsuitable, has already found expression in many of the more recent textbooks, e. g. H. J. Klein, Physische Geographie, p. 341; A. Supan, Grundzüge der physischen Erdkunde, 8vo, Leipzig, 1884, p. 188 et seq.; S. Günther, Lehrbuch der Geophysik, II, 8vo, Stuttgart, 1885, p. 455 et seq.

[2] C. Diener, Libanon, 1886, p. 398. The coincidence of movements of the sea and of

The essential problem of this volume has been to determine in what manner and to what extent movements of the Ocean are dependent on those of the earth. In all probability the Ocean is subject to an independent movement which in the course of long periods causes an alternation of positive and negative phases at the equator. We shall be able to discuss this oceanic movement with greater certainty when the stratified series in high latitudes is better known, and when we are able to clearly distinguish the terraces formed by glacial lakes from those of marine origin. These great oscillations are not, however, cumulative in time; on the contrary they are compensatory. The persistent continuance of a continental surface is in the main the result of local subsidences of the earth's crust, which time after time open up fresh abysses for occupation by the sea, and lower the general level of the strand. Every eustatic negative movement of this kind increases the fall of all the rivers which enter the sea, stimulates afresh the denudation of the dry land, accelerates the transportation and deposition of sediments, and thus induces a heightened eustatic positive movement. The oceanic oscillation has the same effect when it is negative, and even the positive oscillation contributes to the formation of sediment, in so far as it assists in erosion. Thus there is an alternate play of forces. The effect of eustatic subsidences and the deposition of sediments is cumulative, and in the course of geologic periods the eustatic negative movements obtain the predominance. In this matter the folding of the mountain chains plays only a secondary part.

The structure of the Pacific shores shows that this Ocean was already in existence during the Trias epoch, and since then it has continually lost in extent. The structure of the regions surrounding the Atlantic shows that its outlines were determined at a later period, but since the Cretaceous epoch this Ocean also has been reduced in area. The Mediterranean is surrounded by traces of negative movement which extend from central Europe to Persia, marking the alternating phases of progressive restriction; its lowest level was reached between the Miocene and Pliocene. It would be possible, were it desirable, to enter still further into details, and we look forward to a time when the feeble development of negative traces in the regions of the Black Sea and the northern Adriatic will serve as a datum for the more exact determination of the age of these subsidences[1]. Thus the land has

the lithosphere suggested by Löwl leads to ingenious conclusions, but I know of no case in which they could be actually applied; Die Ursache der säcularen Verschiebungen der Strandlinie, Vortrag, 8vo, Prague, 1886.

[1] On the coast of Istria deposits of red earth are encountered, into which beds of sea shells and small pebbles are intercalated; they occur, however, at so trifling a height that the intercalation might have been produced by some disturbance of the sea; Stache, Verh. k. k. geol. Reichsanst., 1872, p. 221; at Pola at a height of one or at most two feet; Marchesetti, Boll. Soc. Adriat., Trieste, 1882, VII, pp. 303, 304, note; at the southern extremity of Istria at a height of one meter.

become habitable owing to the preponderance of negative movements. It is in the history of the seas that we discover the history of the continents.—

Our voyage of inquiry through libraries and literature is now at an end, and we return to the sublime spectacle which served us as our starting-point, the beach and the long inflowing roll of the Ocean waves. Still the mighty chorus resounds; still, and at the same level, the rising tide pauses before it recedes, and the ebb before it returns. And at this same level the ebb and flood have paused, without sensible change, as far back as man can penetrate into the past of his own race.

We have been taught that it is not so, that extensive parts of the planet are slowly rising by vertical upheaval, others as slowly sinking, while some great fragments of the crust, such as Scandinavia, Greenland, Australia, and New Zealand, are subject to a tilting movement; that South America and Norway have been elevated by jerks; that these activities are still in progress and are accomplished at a measurable rate.

It is not, however, that Sweden is rising, but the enclosed Baltic sea, dependent on climatic influences, is gradually emptying, as it passes through a phase of increasing diminution; and it is from this cause that the strand-line sinks lower and lower as it becomes increasingly remote from the Baltic entrance. In the Igalliko fjord of Greenland the alleged displacement cannot be maintained. The oscillations which have left their mark on the columns of the temple of Serapis at Pozzuoli were produced by local movements within the crater of an expiring volcano. They were not felt in the city of Naples, notwithstanding its proximity, and have nothing in common with the horizontal strand-lines which surround the shores of Italy. While in case after case the convincing force of each individual example is weakened or destroyed, on the other hand phenomena confront us which testify to the stability of the existing state, which has endured since the remotest period of human tradition, or since a period even earlier still; in hundreds of localities the sea itself has graven its mark deep in the rocks at the level of the tide.

For thousands of years the fall of the Nile has remained unchanged; the situation of its mouths is still the same; the Bahr Yussuf continues to flow into lake Moeris, sacred to the crocodile, and the Fresh-water canal still traverses the valley of the Seven Springs. The bar extending from the promontory of the Casius across which Moses probably passed with the Israelites is still in existence. The spit in the sea of Azov, and that of Perekop, known to antiquity as the Course of Achilles, were in their present position thousands of years ago. The Roman roads lie on the littoral bars of Tuscany, and the ancient emissary of Cosa still bears away the waters of the lagoons. It is to a still more remote epoch that we are taken by the older bars which lie in the midst of alluvial land behind the existing line of the surf, in the delta of the Po and the Adige to the north of Comacchio,

outside the mouth of the Rhone at Aigues-Mortes, beyond Mobile bay at the mouth of the Mississippi, as well as by that great accumulation built up by the cold current from the north, which provides a foundation for the Keys of Florida as far as the Tortugas. Válmíki, the poet of the Rámáyana, the inspired painter of animate and inanimate nature, and of the human soul as well, has shown what mystery attached, even in his time, to that long bar, the rent fragments of which extend at present from the mainland to Ceylon. Thousands of years of rest were necessary to build up the vast stretch of alluvial land which extends from Ph'nom Baché along the lower Me-kong, to isolate the gulf and convert it into inland lakes, and to create the river Tonlesap which flows during one part of the year from the Me-kong into the lakes, during the other part from the lakes into the Me-kong and out into the sea. The regions described in the ancient Chinese accounts do not extend as far as the sea border, but Richthofen's study of the Yü-king shows us that four thousand years ago the fluvial network of the great plain presented the same fundamental features as to-day, and was probably subjected to inundations fully as devastating as those of our times. Measurable changes along the coast are, therefore, apart from various meteoric influences, confined to loss of land through the erosive action of the sea; to gain of land from the deposition of sediment; to sudden local subsidence of large tracts of alluvial land covered with forest or buildings; to local oscillations in the vicinity of volcanos; and finally, but only in rare cases, to true dislocations affecting the coast, as occurred in Cook strait in New Zealand in 1856.

Yet the level of the strand has often changed, and every grain of sand which sinks to the bottom of the sea expels, to however trifling a degree, the Ocean from its bed. But who would think of expressing in figures the extent of this effect? A considerable lowering of the strand has taken place around the North sea since the last retreat of the ice, but from the Scheldt to the Vlie the remains of Roman walls lie at present outside the dunes; they probably indicate the wandering of the dunes, but prove a change in the height of the strand-line just as little as the fort of the Vikings at Romö. But what are a few thousand years in the course of planetary events? And when we see the 'gates of the coast' between the gulfs of Messenia and Laconia still standing where they stood two thousand years ago, how shall we find a measure for the ages required by the sea, supported though it is by the work of rain and rivers, to wear away whole mountain ranges and entire continents, and to deposit on the levelled down folds thousands of feet of fresh sediment? Yet this it had already accomplished, even before the Silurian epoch, in Texas, in northern China, and in other vast territories. During the Carboniferous epoch, folded ranges were elevated, completely planed down and again covered horizontally with carbonaceous sediments.

The astronomer, in order to render conceivable the immensity of celestial space, points to the parallelism of the stellar rays or to the white clouds of the Milky Way. There is no such means of comparison by which we can illustrate directly the great length of cosmic periods, and we do not even possess a unit with which such periods might be measured. The distance in space of many stars from the earth has been determined; for the distance in time of the latest strand-line on Capri or the last shell-bed on Tromsö, we cannot suggest an estimate even in approximate figures. We hold the organic remains of the remote past in our hand and consider their physical structure, but we know not what interval of time separates their epoch from our own; they are like those celestial bodies without parallax, which inform us of their physical constitution by their spectrum, but furnish no clue to their distance. As Rama looks out upon the Ocean, its limits mingling and uniting with heaven on the horizon, and as he ponders whether a path might not be built into the Immeasurable, so we look over the Ocean of time, but nowhere do we see signs of a shore.

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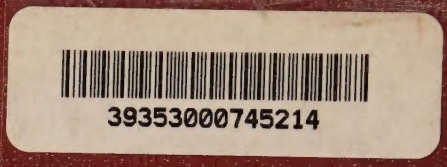
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